UNITED STATES AIR FORCE
KELLY AIR FORCE BASE
SAN ANTONIO, TEXAS

DRAFT FINAL
Zone 4 Corrective Measures Study

Prepared for: **Kelly Air Force Base**
San Antonio, Texas
F41624-97-D-8019-0114

Prepared by: CH2MHILL
The Spectrum Building
613 Northwest Loop 410, Suite 200
San Antonio, Texas 78216

155764

March 2002

E082001003DFW

Contents

Tables

Figures

Acronyms and Abbreviations

AFB	Air Force Base
AFBCA	Air Force Base Conversion Agency
AOC	area of concern
bgs	below ground surface
BRAC	Base Realignment and Closure
BTEX	benzene, toluene, ethylbenzene, and xylene
BZAA	Benzo(a)anthracene
BZAP	benzo(a)pyrene
BZBF	benzo(b)fluoranthene
BZGHIP	benzo(g,h,I)perylene
BZKF	benzo(k)fluoranthene
CEI	Compliance Evaluation Inspection
CFS	cubic feet per second
CLP	Contract Laboratory Program
CMS	Corrective Measure Study
COC	contaminants of concern
CRDL	contract-related detection limits
CVOC	chlorinated volatile organic compound
DCE	dichloroethene
DDD	1,1-bis(chlorophenyl)-2,2-DCA
DDE	1,1-bis(chlorophenyl)-2,2-DCE
DDT	1,1-bis(chlorophenyl)-2,2,2-TCE
DLA	Defense Logistics Agency
DNAPL	dense nonaqueous-phase liquid
DOD	Department of Defense
DQE	data quality evaluation
DRMO	Defense Reutilization and Marketing Office

ERA	Ecological Risk Assessment
FOD	frequency of detection
GIS	geographic information system
GKDA	Greater Kelly Development Authority
GWP-Ind	groundwater protection criteria for soils at industrial sites
HHRA	human health risk assessment
INP123	indeno(1,2,3-c,d)pyrene
IRP	Installation Restoration Program
IWCS	industrial wastewater collection system
LNAPL	light nonaqueous-phase liquid
MEK	methyl ethyl ketone
mg/kg	milligrams per kilogram
MS	matrix spike
MSC	media-specific concentration
MW	monitoring well
NCP	National Contingency Plan
OU	operable unit
OWS	oil/water separator
PAH	polynuclear or aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo-p-dioxin
PPCF	polychlorinated dibenzofuran
PCE	tetrachloroethene, also perchloroethene
Pg/g	picograms per gram
POL	petroleum oil, and lubricant
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RFI/CMS	RCRA Facility Investigation/Corrective Measures Study
RI	Remedial Investigation
RRS	Risk Reduction Standard

SA/ALC	San Antonio Air Logistic Center
SAATSC	San Antonio Air Technical Service Command
SAI-Ind	soil-to-groundwater cross-media protection MSC for industrial sites
SOV	soil organic vapor
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TAC	Texas Administrative Code
TCA	trichloroethane
TCDD	tetrachlorodibenzo-p-dioxin
TCE	trichloroethene
TEC	Tropicana Energy Co.
TEQ	toxicity equivalent quotient
TNRCC	Texas Natural Resource Conservation Commission
TOC	total organic carbon
TOX	total halogenated organics
TPH	total petroleum hydrocarbons
TRRP	Texas Risk-Reduction Program
µg/kg	micrograms per kilogram
USAF	United States Air Force
UST	underground storage tank
VOC	volatile organic compound

Executive Summary

This report presents the Corrective Measures Study (CMS) portion of the Resource Conservation and Recovery Act of 1976 (RCRA) corrective action process to identify and evaluate potential remedial alternatives for the releases that have been identified through the RCRA Facility Investigation (RFI). Remedial alternatives were developed and evaluated for the MP Source area, SS051 Source area and the off-base plume associated with the two source areas.

Recognizing the potential effects to the surrounding community from off-base solvent plumes near Kelly Air Force Base (AFB), the Kelly Air Force Base Conversion Agency (AFBCA) conducted an innovative and proactive approach to help identify the most effective and acceptable remedial alternative to clean up the Zone 4 off-base plumes. AFBCA decided to include public participation at the onset of the decision process before the document is submitted. Several public workshops were held to gather public comments and concerns; the remarks were recorded and incorporated into the technical decision process.

Twelve corrective measure alternatives (CMAs) were developed for the off-base solvent plume. The CMAs consist of the following remedial technologies, or a combination of the technologies: pump and treat, reactive walls, in-situ oxidation, air sparging and vapor extraction, enhanced biodegradation, phytoremediation, and natural attenuation. Each of the 12 CMAs was evaluated using community concerns and technical criteria. Six of the 12 CMAs was found to meet some or most of the community concerns and technical criteria. Further evaluation of these six CMAs found that a combination of the following technologies will most likely meet the community concerns and technical criteri: existing source control systems, limited reactive walls or treatment zones, and pump and treat using vertical wells at high concentration areas. Natural attenuation will also continue for very low concentrations in down-gradient areas of the current plume.

Seven CMAs were developed for the on-base MP and SS051 source areas. These CMAs were also evaluated using the technical criteria. The CMAs consisted of the following remedial technologies, or a combination of the technologies: pump and treat, reactive walls, in-situ oxidation, air sparging and vapor extraction, enhanced biodegradation, natural attenuation. Existing source control systems, monitoring and natural attenuation are identified as the preferred alternatives for the on-base source areas.

SECTION 1.0

Introduction

1.1 Purpose and Scope

The purpose of the CMS portion of the RCRA corrective action process is to identify and evaluate potential remedial alternatives for the releases that have been identified through the RFI.

Recognizing the potential effects to the surrounding community from off-base solvent plumes near Kelly AFB, the Kelly Air Force Base Conversion Agency (AFBCA) conducted an innovative and proactive approach to help identify the most effective and acceptable remedial alternative to clean up the Zone 4 off-base plumes.

Typically, a CMS does not include public participation until the draft final CMS is submitted to regulatory agencies. AFBCA, however, decided to include public participation at the onset of the decision process before the document is submitted. Several public workshops were held to gather public comments and concerns, the remarks were recorded and incorporated into the technical decision process.

This CMS describes the processes through which technical solutions are being evaluated to determine the best corrective action for cleaning up the solvent plumes emanating from Installation Restoration Program (IRP) Sites SS051 and MP, recognizing that the cleanup of the off-base plumes are of primary importance to the surrounding community.

The technical solutions being evaluated consider the direct application of technical solutions to the off-base plumes as well as remedial action at source areas SS051 and MP. Remedial action at the source areas is being considered because they are expected to significantly decrease cleanup times in off-base areas.

1.2. Background

The United States Air Force (USAF) assesses past hazardous and industrial waste release sites on USAF installations through the IRP. The IRP develops remedial actions for sites that may pose a threat to human health or the environment. The process for characterizing the release, evaluating the likelihood of a threat to human health or the environment and selecting a remedy is known as the Remedial Investigation and Feasibility Study (RI/FS) process, which is patterned after the United States Environmental Protection Agency's (EPA) Superfund Program.

Kelly AFB has a hazardous waste permit for the closure and postclosure activities at hazardous waste sites on the base. The permit dictates that RI/FS reports be submitted in a format consistent with the RCRA. The RCRA term for an RI/FS is RCRA Facility Investigation and Corrective Measures Study (RFI/CMS).

The RFI for IRP Zone 4 (East Kelly AFB) at Kelly AFB has been submitted as a draft final (CH2M HILL, 2001). The Zone 4 RFI report presents the results and conclusions for IRP Zone 4 Operable Units (OUs) 1 and 2. OU-1 includes on-base soil and OU-2 is defined as the groundwater affected by IRP Sites SS051 and MP. The Zone 4 RFI report accomplished the following objectives:

- Evaluated the nature and extent of groundwater contamination from IRP Sites MP and SS051
- Evaluated the nature and extent of soil contamination at Site SS051, Area of Concern (AOC) MW125, AOC MW160 and AOC Yard 68
- Compared contaminant concentrations to applicable regulatory standards
- Collected sufficient data to support a CMS

The Zone 4 RFI does not address the dense nonaqueous phase liquids (DNAPLs) and the associated dissolved-phase contamination within the slurry containment wall at IRP Site MP. Conditions within the slurry wall are addressed in the RFI for Building 258 (Science Applications International Corporation, Inc. [SAIC], 2000).

In addition to the Zone 4 RFI, the RFI/CMS efforts are supported by a Draft Final Zone 4 Ecological Risk Assessment (ERA) (CH2M HILL, 2001) and a Draft Final Zone 4 Human Health Risk Assessment (HHRA) (CH2M HILL, 2001), which have been submitted as individual reports.

The Zone 4 RFI concluded that soil remediation was not needed at IRP Site SS051, AOC MW125, AOC MW160 and AOC Yard 68. This report documents the CMS for groundwater affected by IRP Sites SS051 and MP (i.e., IRP Zone 4 OU-2).

1.3 Objectives

The following are the objectives of this CMS:

- Briefly discuss the historical operations at East Kelly (Zone 4) and IRP Site MP. Present the current understanding of the hydrogeology and the nature and extent of contamination at East Kelly (Zone 4), Site MP, and off-site areas affected by IRP Sites SS051 and MP. Also, briefly discuss existing source control systems at Sites SS051 and MP.
- Present the preliminary corrective action objectives (CAOs) for reducing groundwater contaminant concentrations to acceptable levels.
- Identify, screen and evaluate applicable technologies. Screening criteria include effectiveness, implementability and relative cost (cost factors were not used to eliminate any technology).
- Develop, compare and contrast the most feasible CA alternatives.
- Recommend the most promising corrective action based on the results of the comparison of developed alternative

SECTION 2.0

Community Involvement

2.1 Introduction

This section provides information on the AFBCA community involvement program related to the development of a community-based solution for the shallow groundwater contamination originating from Zone 4 on the former Kelly AFB. It describes the analysis and decision process and the various ways the AFBCA gathered public input. It also summarizes public input received to date on related issues such as health, property values and economic concerns.

2.2 Background

Kelly AFB closed on 13 July 2001. The Environmental Management (EM) function at the former Kelly AFB was transferred from San Antonio Air Logistics Center (SA-ALC)/EM to the AFBCA in December 1999. With the transfer of authority, AFBCA assumed the responsibility for managing the environmental cleanup program not only to protect human health and the environment, but also to implement a solution that is acceptable to the community. With this goal, the AFBCA began a specialized outreach program to help develop a community-based cleanup solution for off-base shallow groundwater contamination originating from Zone 4.

The AFBCA is taking an innovative and interactive approach to identify the best remedial alternative to clean the Zone 4 off-base shallow groundwater plume. The typical regulatory approach to choosing the cleanup alternative does not include public involvement until near the end of the process. In this case, AFBCA included the public early in the process. The concerns and ideas of the community have been gathered through public workshops and meetings. Concerns and ideas were and are being considered in the decision process in several ways, such as in the evaluation criteria and potential options for a community-based solution.

AFBCA has sponsored seven public meetings to gather information and has given over 175 one-on-one and small group meetings with various stakeholders. Individual presentations were made to federal, state, county, and city elected officials; various community organizations; chambers of commerce members; area businesses and agencies; environmental regulators; school districts and Parent-Teacher Associations (PTAs); church groups; neighborhood associations; news media and individual residents of the surrounding neighborhoods. An Environmental Public Information Line was established and widely advertised for the public to record concerns and make inquiries. Information was also gathered from personal letters, telephone calls and visits with AFBCA staff. These comments and questions helped to develop potential evaluation criteria and solutions. Criteria and potential solutions were presented to the Kelly Restoration Advisory Board (RAB) at their meetings in September and November 2000, and January and February 2001.

AFBCA also gave presentations regarding cleanup options and public health issues to the San Antonio City Council in January and February 2001. After discussion, the Council directed the City of San Antonio (COSA) staff to obtain the services of a technical consultant. The task of the consultant was to provide an independent review of the cleanup options developed by the AFBCA. The City's consultant, Zephyr Environmental Corporation, provided a review of the cleanup options and made several recommendations, which are summarized in Section 2.4.3.

2.3 Public Workshops

The AFBCA gathered public comments and provided current information through seven public workshops. Those workshops are outlined in Table 2.1.

TABLE 2.1
Dates and Locations of Public Workshops and Public Comment Meetings
Zone 4 Corrective Measures Study, Former Kelly Air Force Base, Texas

DATE	LOCATION	TOPIC
June 14, 2000	Brentwood Middle School	Background information workshop
July 18, 2000	Dwight Middle School	Information workshop
August 28, 2000	Kennedy High School	Health, property values, shallow groundwater, technical solutions
September 25, 2000	Kennedy High School	Decision process, criteria, potential solutions
November 1, 2000	Kennedy High School	Twelve potential solutions
January 31, 2001	Kennedy High School	Twelve potential solutions
February 21, 2001	Kennedy High School	Six most feasible options

2.3.1 Background on Public Workshops

At each meeting, environmental experts from the Air Force presented current information, answered questions and received comments in both English and Spanish. At the last three workshops, simultaneous interpreters were available for those who wished to use that service. Professional third-party facilitators were an important element at each meeting. Facilitators provided an orientation for the public to the workshop and facilitated dialogue. One facilitator was bilingual and facilitated Spanish-speaking workgroups. Posterboards, which were also available as handouts, informed the public of the following:

- The decision process
- Various technologies that might be applied in the cleanup
- Regulatory and community-based criteria
- Public concerns and ideas

- Draft potential cleanup options
- Least and most feasible technical options
- Potential options to address concerns about health, property values, economics and redevelopment

Numerous handouts in English and Spanish on meeting topics were produced and available at every workshop. The handouts included the following:

- Fact sheets on the primary chemicals of concern
- Groundwater cleanup technologies
- Description of the shallow groundwater in Bexar County
- Modeling information
- Glossary of terms
- Bookmarks that advertised the public information phone line
- Evaluation criteria
- Evaluation matrix
- Information on the RAB and information repositories

Other agencies had displays or staff at information tables to answer questions and provide information. Agencies represented in this way at various workshops included the following:

- San Antonio Metropolitan Health District (SAMHD)
- Edwards Aquifer Authority (EAA)
- San Antonio River Authority (SARA)
- San Antonio Water System (SAWS)
- San Antonio Department of Public Works
- Prudential Alamo Realty
- South Trust Mortgage
- Southtown Realtors
- Bexar Appraisal District (BAD)
- Kelly Parkway Corridor Study
- County Agricultural Extension Service
- Greater Kelly Development Authority
- Interstate Technologies Research Center

- Kelly RAB

All meetings were advertised in several ways. Newspaper display ads were published in English and Spanish in the *San Antonio Express-News*, *La Prensa* and the *Southside Reporter*. AFBCA sent postcards to a mailing list of approximately 25,000 residences, businesses, elected officials and other interested parties. AFBCA also issued news releases and public service announcements.

Attendees were encouraged to submit comments in various ways. Comments were recorded on flip chart sheets. Comment forms were available so people could submit their comments at each meeting or by mail or fax to AFBCA later. At two meetings, a laptop computer was available. A staff person recorded comments dictated by an attendee, who could take a hard copy of their comments with them. Comments were also accepted through telephone calls, letters and discussions at individual meetings. Similar comments or concerns were organized into six basic topics: shallow groundwater, health, property values, technology, public participation and miscellaneous topics.

Another short form was also available asking for feedback on each meeting. As a result of feedback received, the meeting format was changed to make it more conducive for the public participation.

2.3.2 Workshop Topics

The first two meetings, held in June and July of 2000, provided background information on the shallow groundwater and the contamination in the shallow groundwater that originated from the former Kelly AFB. Descriptions were given of the known locations of contamination within the shallow groundwater zone and of the existing cleanup systems that prevent additional contamination from spreading off base. About 70 members of the public attended the June meeting and about 65 attended the meeting in July.

In August, United States Congressmen Ciro Rodriguez and Charlie Gonzalez attended a public meeting. The goals of this meeting were:

(1) To continue sharing information about the technologies and considerations in using each (i.e., construction effects such as noise, dust, traffic disruption, tearing up roads, possible use of personal property, etc.), and

(2) To gather more input on technologies, the shallow groundwater cleanup, health issues, property values, and any other concerns. Poster boards from previous meetings were displayed and the handouts were available. Technical staff and facilitators were available to address specific technologies and topics. Comments were recorded throughout the evening at the topic tables and at the Congressmen's booths. A criteria-rating matrix was distributed to gather input on what would constitute a good cleanup plan for the plume. About 200 members of the public attended.

In September, the format of the workshop changed. The past workshops were set up so attendees could move about the room at will and ask questions one-on-one at various topic stations. At the third meeting workgroups were established as people arrived. One workgroup was conducted in Spanish for those who were more comfortable conversing in that language. A facilitator and recorder were assigned to each workgroup. The facilitator led the discussion as each workgroup reviewed the decision process, evaluation criteria and possible options. After this initial presentation, each workgroup moved with its facilitator to poster stations to obtain information and ask questions about specific technologies. Each workgroup then reconvened to discuss what they had heard and ask more questions. Comments and questions were recorded for each workgroup. At the end of the evening, the meeting facilitators conducted a "report back session." They recorded on flipchart sheets the summaries of discussion from each workgroup. Attendees were also invited to make individual closing remarks that were recorded. Again, all comments were added to the table of questions and concerns. Approximately 87 members of the public attended.

For the November public meeting, the AFBCA presented 12 potential technical options. This meeting was conducted in a small group format at a series of poster stations where subject-matter experts explained the intricacies of each particular technical, health or property option. A facilitator led each small group of participants around the room to each poster station. Members of the community stated their likes, dislikes and recommendations for each of the options at the poster stations. A poster area identified as "Kelly Shallow Groundwater 101," provided basic background information on the contamination for those members of the public who had not attended previous meetings or were unfamiliar with the issues. Approximately 150 members of the public attended this meeting.

At the January 31 workshop and February 21 public comment meeting, the AFBCA provided new information. The new information included a shortened list of technical options carried through for further analysis and a draft list of options to address community concerns about health, property values and other concerns.

The AFBCA considered public input received prior to that time and conducted computer modeling and analyses. The result was a list of the most and least feasible technical options. AFBCA presented these two categories of options for public comment at these two meetings. More detailed analysis was provided for those technical options considered most feasible. This included brief responses to the major review criteria such as time, cost and feasibility. Conceptual drawings of the decreasing extent of the plume at five, 10, and 15 years were provided. In addition, a table listed the six most feasible options and the percentage of the contamination that might be cleaned up in five, 10, and 15 years.

The AFBCA also considered specific ideas from the public about health and property values. The result was a draft list of options to address those issues and information on why other ideas might be deferred. Comments were requested on all options and the analyses of them.

All options were presented on posters and as handouts. Posters from past public workshops were available at both meetings to explain the nature and extent of the contamination to members of the public who might not have been at previous meetings. One or two staff members were available at each poster station to answer questions. Comments were recorded on flip charts scattered throughout the room, on comment cards and on a laptop computer.

At the February public comment meeting, a court reporter recorded all the proceedings. An administrative law judge from the Air Force presided over the meeting where the public offered comment in a more formal setting. This public comment time was preceded by a summary presentation of the community-based decision process, the most feasible technical options and options to address health and property values. Approximately 70 members of the public attended the January workshop and approximately 40 attended the February meeting. Again, translators were present at both meetings for those who wished to converse in Spanish. Handouts and posters were prepared in both English and Spanish.

2.4 Summary of Public Input Received to Date

Concerns and comments received from the public since February 2000 were documented in various ways, including comments recorded on flipcharts at the public information meetings, gathering comment forms, recording comments from RAB meetings, and logging input from phone calls and briefings for community groups. Hundreds of comments were received and organized into six major categories: health, property, technical questions, cleanup options, shallow groundwater and miscellaneous issues.

Public input was incorporated into the decision process in two ways: first, as criteria against which to evaluate potential options, and, second, as potential options to address environmental issues and public concerns. Criteria and options were presented in the *Decision Criteria Matrix*. The matrix lists potential solutions and the criteria against which all potential solutions must be evaluated. The criteria included those required by state and federal regulations. One of the regulatory criteria is community acceptance. Input from the public was listed as subcategories under this criterion. With this detail provided by the public, the AFBCA and the regulatory agencies can better determine what options might be most publicly acceptable. Public acceptance is not meant to be a vote or consensus of public opinion; instead, it should reflect the diversity of opinion among all members of the public. Therefore, the many public comments help the government agencies understand varied opinions.

Following are summaries of three major topics of public concern (health, property and miscellaneous issues) that the AFBCA wishes to address beyond that required by environmental regulations. Each summary includes both criteria and potential options that the AFBCA is evaluating and on which further public comment will be sought. See Section 7.0 of this draft final *Corrective Measures Study* for information on the potential technical cleanup options.

2.4.1 Public Health Issues

The public has shared with the Air Force their concerns about health issues and ideas on how to address these issues. The following are the general community concerns developed from public comments and regulatory requirements regarding public health:

- The remediation option should use techniques that protect people and the environment during its construction and operation
- The groundwater should be cleaned to drinking water standards
- The groundwater cleanup levels should protect human health and the environment
- The groundwater should be cleaned to pristine conditions

- The Edwards Aquifer should be protected
- There should be testing to ensure home-grown foods are safe to eat
- Public health concerns should be addressed during the cleanup or referred to appropriate agencies
- The community would like the AFBCA to consider other uses for the cleaned-up water from the treatment plants.

The following table provides a summary of specific concerns from the public and the ways the AFBCA has addressed them or plans to address them. These potential actions were provided to the public for comment at the public workshop on January 31, 2001 and the public comment meeting on February 21, 2001. They were also discussed at City Council sessions on January 25, 2001 and February 22, 2001.

Public Concern	Action by AFBCA	Notes
The community stated that the government should pay for personal healthcare costs.	AFBCA has provided funding to SAMHD to establish the Public Center for Environmental Health (PCEH) to address community health issues with surveys, clinics and research. The PCEH will provide health education for the public and health professionals.	At this time, there is no established link between the contamination and the community health effects. Current Government policy does not allow for personal healthcare payments under these circumstances.
The community indicated that the government should conduct other health studies of the workers and community.	The Air Force provided funding for ATSDR to perform a Public Health Assessment (PHA) which was completed in 2001. SAMHD is working with the Air Force health sciences center at Brooks AFB on a Kelly worker mortality study. The health sciences center at Brooks AFB is also conducting a study of amyotrophic lateral sclerosis (ALS), also known as Lou Gehrig's disease.	Additional studies may occur depending on the outcome of the PHA and other studies mentioned above

Public Concern	Action by AFBCA	Notes
The community wanted the government to provide bottled water to the elderly and children.	If any construction action by the AFBCA prevents access to the municipal water supply to property for an extended period, bottled water will be provided.	At this time, there is no evidence that anyone is drinking the shallow groundwater. Since there is no exposure to contaminated water and no one is known to be drinking contaminated water, government policy does not allow payment for bottled water.
The community requested that the AFBCA sample soil, water, air and edible plants on personal property located within the plume area.	The AFBCA, in partnership with the SAMHD, has conducted limited sampling of pecans and other produce on private property. The results of that study can be obtained from the SAMHD. More sampling may be conducted in the future.	
The community indicated that the Edwards Aquifer recharge zone should be protected.	The recharge zone is in the northern part of Bexar County and is not part of the area affected by the Kelly groundwater contamination. The Air Force proposes to continue to share information with the EAA and SAWS. This will aid them in making decisions that affect the recharge zone.	

The Air Force will continue to work with the SAMHD, COSA Public Works, GKDA, EPA and TNRCC to ensure that all health-related issues are addressed during cleanup.

2.4.2 Property Issues

The public has shared concerns about how they believe the shallow groundwater contamination affects local property values. The following community concerns were developed from public comments regarding property values:

- The option selected should address both on-base and off-base contamination
- Positive effects are sought for homeowners and businesses: the community would like measures to be taken to preserve or restore property access during implementation of the remedy is considered
- Property value concerns should be addressed or referred to appropriate agencies

The following table describes potential actions to address concerns about property. Ideas provided by the public are summarized and potential options were developed to address them. Additional comments on some options are also provided.

Public Concern	Action by AFBCA	Notes
The community requested that the AFBCA provide educational outreach and data to lenders, realtors and tax appraisers.	The Air Force will prepare, in cooperation with other agencies, a program to provide data to and educate and inform lenders, realtors and tax appraisers. They will also refer calls to the appropriate agencies.	
The community indicated that AFBCA should plug and abandon wells located in the shallow groundwater zone.	The Air Force is currently working with SAWS and Bexar Metropolitan Water District to locate any private wells in the shallow groundwater and properly plug or abandon them at Air Force expense.	At this time, there is no evidence that anyone over the plume is drinking the shallow groundwater. SAWS and Bexar Metropolitan Water District provide drinking water from the Edwards Aquifer.
The community would like the AFBCA to monitor property values.	The Bexar County Appraisal District (BCAD) prepared a market summary data report for Appraisal Year 2000 that concluded that at that time there was no demonstrable negative market impact on property values as a result of groundwater contamination. The AFBCA will continue work with BCAD to monitor property values.	The Air Force believes that property values will be stabilized or improved by plugging the private shallow groundwater wells at government expense. Monitoring of property values should also help.
The community requested that buffer zones be created to separate Kelly industry from the community.	The Air Force will work with GKDA and the COSA to reserve areas that do not already have industry on them that could remain as buffer zones.	
The community expects the AFBCA to coordinate infrastructure improvements with the COSA.	The Air Force will coordinate the cleanup activities with the infrastructure improvement projects of the COSA and the State of Texas.	The Air Force will continue to work with the community to notify them in advance of construction activities, dust control and other issues.

Public Concern	Action by AFBCA	Notes
The community stated that no matter what cleanup option is chosen, the law requires either a deed recordation or ordinance to promote health and safety and restrict access to the shallow groundwater.	The Air Force is working with the COSA on drafting such an ordinance.	
The community requested an independent assessment and monitoring of the shallow groundwater cleanup	The RAB conducted an independent review of the Zone 4 RFI and the ATSDR Public Health Assessment using AFBCA Technical Assistance for Public Participation funds. The U.S. EPA and the TNRCC also oversee all cleanup activity at Kelly. The GKDA has a role in making sure the environmental condition of the property is safe for redevelopment.	The COSA also conducted an independent review of potential cleanup actions for shallow groundwater. This review is discussed in Section 2.4.3.
The community asked if the government would buy out residential property in the plume area.	If the Air Force needs private property to build part of the cleanup system it will follow government regulations for providing fair market value for property needed. This may be through a lease, purchase, right-of-way or easement.	The Air Force will first seek government property on which to put the cleanup systems. Public rights-of-way will be the next choice. Private property will be the last option.

This initial list of potential AFBCA actions was provided to the public for comment at the public workshop on January 31, 2001 and the public comment meeting on February 21, 2001. They were also discussed at City Council sessions on January 25, 2001 and February 22, 2001. All cleanup options include coordination with the City and State transportation, planning and river authorities City and State public works and health departments and the Kelly Parkway Authority on cleanup activities or individual questions. The preferred alternative will also address both on-base and off-base contamination and protect human health and the environment.

2.4.3 City of San Antonio (COSA) Comments

The COSA Department of Public Works (DPW), SAMHD and AFBCA made presentations regarding cleanup and health issues to the San Antonio City Council on January 25, 2001. The DPW staff continued their review of AFBCA data and made another presentation at the City Council session in February2001. After discussion, the Council directed the DPW to search for a technical consultant who had not provided support to the Department of

Defense. The task for the consultant was to review the cleanup options developed by the AFBCA and make recommendations to the City.

The City selected Zephyr Environmental Corporation to perform the review in August 2001. They reviewed the investigation work completed at the former Kelly AFB, interim measures installed, groundwater modeling performed, the human health risk assessment prepared for Kelly, and the current options being considered by the AFBCA for remediation. Zephyr performed this review within 30 days, and presented the results to the City Council in October 2001. The following table summarizes the recommendations made by Zephyr and the AFBCA action taken.

Zephyr Recommendation	AFBCA Action
AFBCA should:	
1. Install vertical wells instead of horizontal wells in hot spots.	AFBCA included vertical wells as a component of the preferred alternative.
2. Plug and abandon privately owned shallow groundwater wells within the area of the plume.	AFBCA has begun a cooperative effort with SAWS and SAMHD to locate, obtain access to and plug or properly abandon such wells at Air Force expense.
3. Conduct routine soil vapor monitoring beneath slabs in the area of the plume.	AFBCA is working with the COSA Environmental staff and the SAMHD to locate and obtain access to sites with slabs for soil vapor sampling.
The City of San Antonio should:	
1. Provide institutional controls to prohibit use of shallow groundwater.	AFBCA is working with the City to develop an ordinance.
2. Participate in the study being conducted by the Bureau of Economic Geology (BEG).	AFBCA is providing funding for the BEG and coordinating with the U.S. Geological Survey, EAA, SAWS, SAMHD, the Bexar Metropolitan Water District and the COSA Environmental staff to assist in this effort.
3. Revise City Code to require double-cased wells for any new Edwards wells drilled in Zone 4.	AFBCA reviewed well completion rules and regulations, which already call for isolating zones of undesirable water. This requirement for all practical purposes requires double casing of the gravel zone, where shallow groundwater is found.
4. Utilize phytoremediation along the San Antonio River.	Phytoremediation was considered and was not part of the preferred alternative because it would not be effective for several years, groundwater contaminant concentrations are very low to nondetectable near the river, and the San Antonio River Authority is in the process of conducting a large improvement project. Modeling results show that the shallow groundwater would already be remediated before the phytoremediation could take effect.

2.4.4 Other Issues

The public has shared with the Air Force concerns and ideas about other issues, such as employment, economic development and Air Force commitment to the cleanup. Other comments were about issues on which the USAF cannot act but can assist other agencies. These include:

- The community is concerned about full-time jobs and job training for the employees of the new tenants.
- The community wants assurance that new tenants will provide equal pay for equal work.
- The community feels that a business incubator should be provided.
- The community indicated that "zero waste production" should be a goal of the new tenants.

In response to concerns about the Air Force commitment to cleanup, all clean-up options include the following:

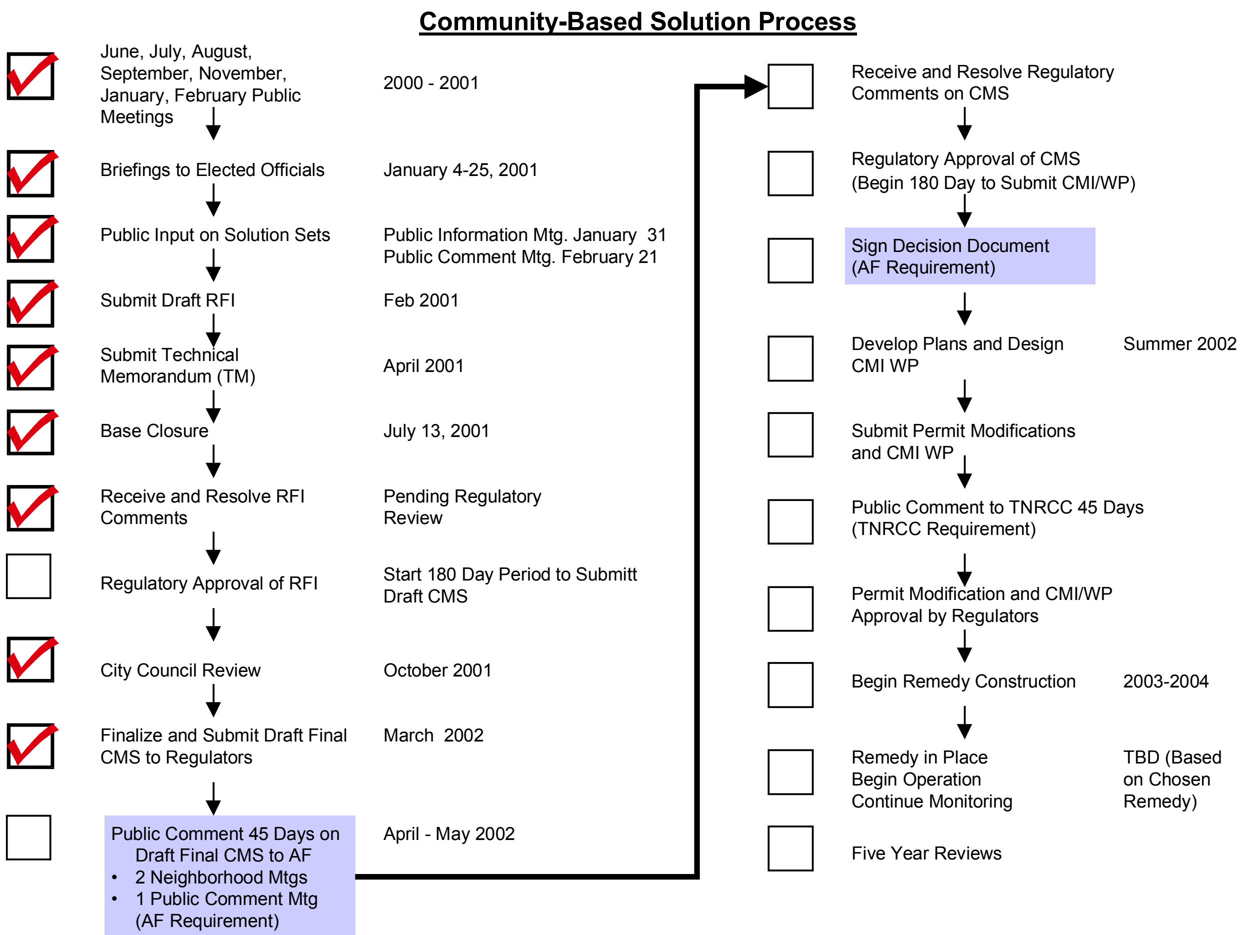
- The Air Force will disclose 100% of the environmental conditions of the property before redevelopment.
- The AFBCA will continue the cleanup of Air Force-caused contamination until it is complete. The cleanup is part of the annual Air Force budget.
- The AFBCA will work closely with TNRCC, the primary agency responsible for enforcing environmental laws and regulations in the cleanup, and the U.S. EPA.
- The public will be strongly encouraged to provide input on clean-up remedy issues to the Air Force before a recommendation is made to the TNRCC.
- The Air Force will continue to coordinate with the City of San Antonio, Bexar County and State of Texas water, planning and public works departments and will also work within the laws for funding and use of government funds.
- Long-term monitoring will be done to maintain an accurate picture of the status of the shallow groundwater.
- The recommended clean-up option is a balance of the shortest time to clean-up, best use of tax dollars, least disruption to the community, and other public and regulatory criteria.
- The Air Force will continue to work with the GKDA to attract and assist industries that use state-of-the-art technology and manage their wastes in ways that are more environmentally friendly.

2.5 Next Steps

A formal public comment period of 45 days will be held to accept input on the draft final CMS. AFBCA will hold public information sessions and public meetings to review the preferred alternative and allow for public discourse. Comments received will be summarized and the responses will be presented in a Responsiveness Summary that will be available to all who provide comments, to information repositories, and on request. The regulatory agencies will also have the public input to review as they consider the cleanup recommendation in the draft final CMS.

Figure 2.1 outlines the long-term process to address the Zone 4 shallow groundwater plume including opportunities for public involvement as well as regulatory requirements.

FIGURE 2.1
Community-Based Solution Process
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas



SECTION 3.0

Current Conditions

This section briefly discusses the historical operations at East Kelly (IRP Zone 4) and IRP Site MP. Following this historical discussion is a description of the current understanding of the hydrogeology and the nature and extent of groundwater contamination at East Kelly (Zone 4), Site MP, and off-site areas affected by IRP Sites SS051 and MP. Also included is a discussion of existing source control systems at Sites SS051 and MP.

3.1 Operational History

3.1.1 East Kelly (IRP Zone 4)

From about 1954 to 1974, the industrial complex for the Kelly AFB aircraft engine maintenance operations was housed at East Kelly. Former engine repair facilities at East Kelly were located in Buildings 3003, 3004, 3008, 3020, and 3052 in the northwest corner of East Kelly. **Figure 3.1** shows the locations of these buildings, East Kelly (IRP Zone 4), and the boundary of Site SS051. Buildings 3004, 3008, and 3020 were leased to St. Philips College in the early 1980s for vocational training facilities and have since been sold to the College. Building 3004 is now the administrative building for the college. Building 3052 has been demolished.

IRP Zone 4 includes a number of potential release sites: one is evaluated in this CMS report (SS051), while others are proceeding to closure separately from this effort, and still others have obtained regulatory closure. **Figure 3.2** shows the locations of each East Kelly IRP site.

3.1.1.1 IRP Site SS004

IRP Site SS004 (formerly IRP Site S-2) is located in the northernmost part of East Kelly and includes two former hazardous waste storage yards, Yard N and Yard 13. Although Yards N and 13 were designated as IRP sites and were closing using the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) process, the TNRCC stated that the site must also be closed under RCRA because the yards were interim-status hazardous waste storage facilities named in the Defense Reutilization and Marketing Office (DRMO) permit. Site SS004 is being addressed in a separate CMS and is not considered to contribute to the groundwater contamination addressed in this CMS.

3.1.1.2 IRP Site SS009

Site SS009 (formerly Site S-7) was an open storage yard located in the southwest portion of East Kelly. The site was used to store non-hazardous materials and was the location of a herbicide spill in the 1970s. An RI (HNUS, 1992b) conducted at this site determined that the site did not pose a threat to human health and the environment, which led to closure for this site in 1997. As a result, this site is not further considered in this CMS.

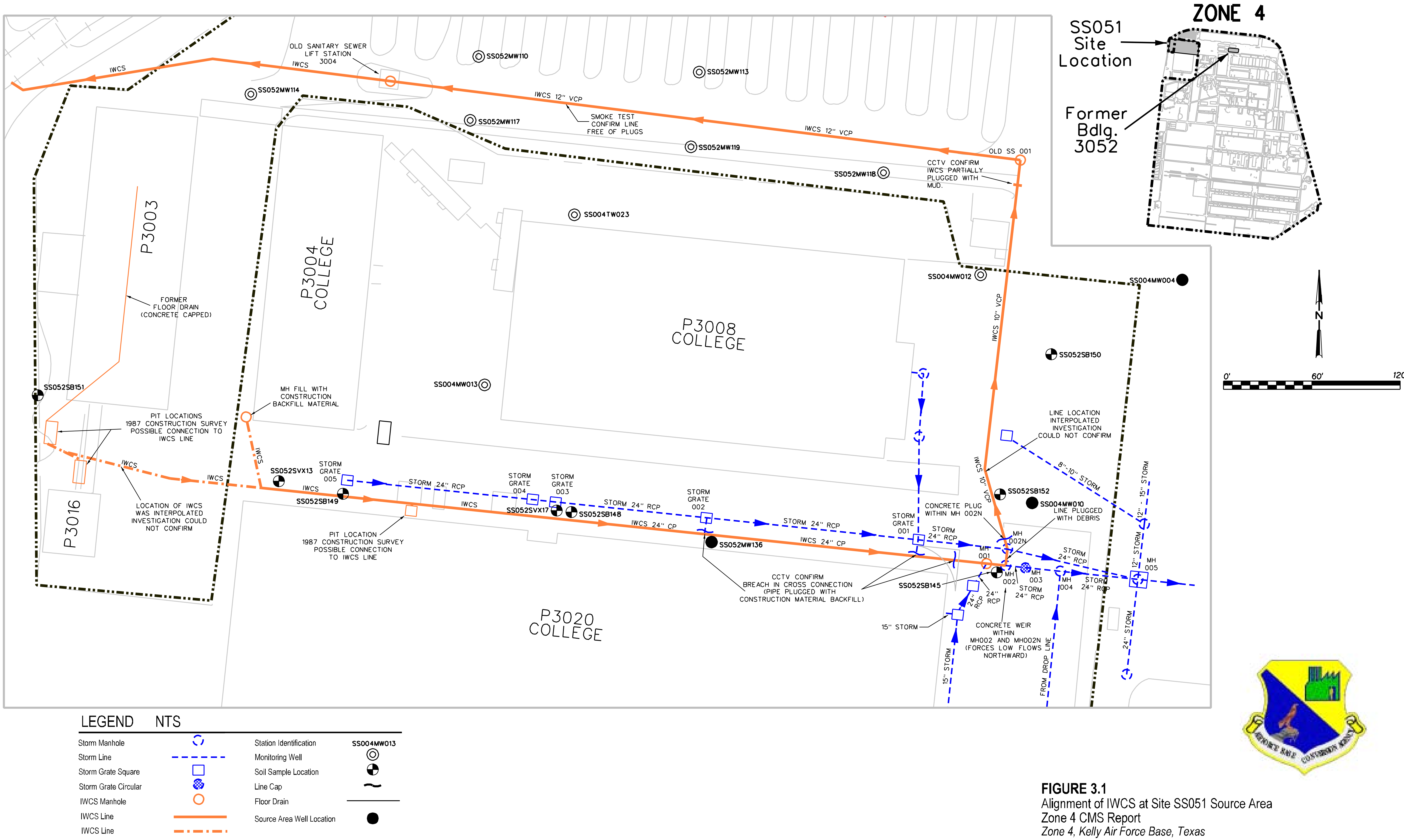


FIGURE 3.1
Alignment of IWCS at Site SS051 Source Area
Zone 4 CMS Report
Zone 4, Kelly Air Force Base, Texas

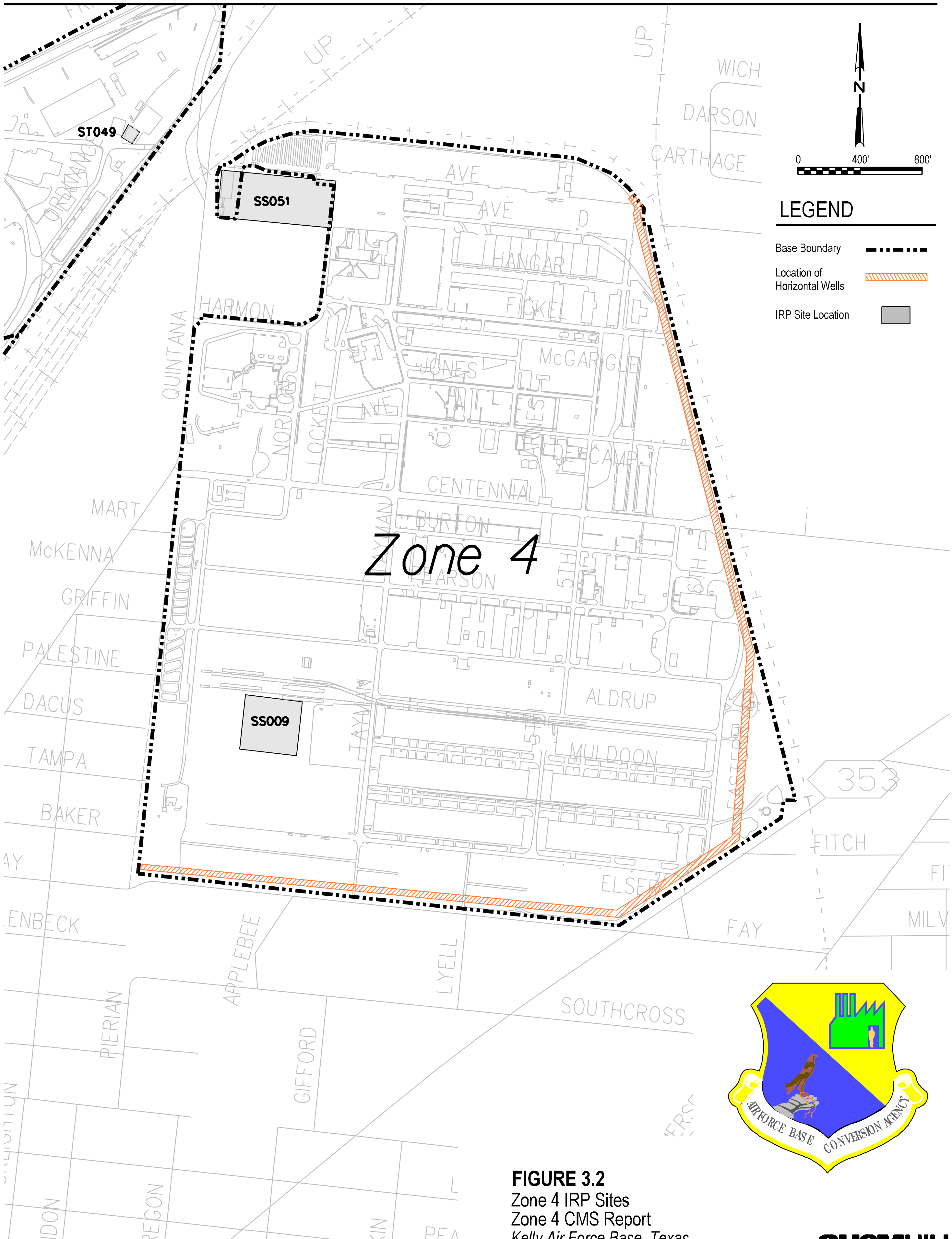


FIGURE 3.2
Zone 4 IRP Sites
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

3.1.1.3 Site SS051

Site SS051 is located in the northwest corner of East Kelly and is associated with releases from the industrial waste collection system (IWCS), an underground piping system formerly used to transfer industrial wastewater. The area around Site SS051 is covered with asphalt, buildings and grass. The IWCS was installed in the 1950s throughout Kelly AFB, including East Kelly. The new collection system was established in part by converting storm sewer and sanitary sewer lines (CH2M HILL, 1996). Waste from former engine repair facilities at East Kelly were connected to the IWCS and transported to the treatment facilities located on Main Kelly. The former pipeline encircles Buildings 3003, 3004, and 3008 (**Figure 3.1**). Buildings were connected to the IWCS, which transported liquid wastes and wastewater to a lift station located north of Building 3003. From there, the wastewater was pumped to a treatment plant on main Kelly AFB. The composition of the waste stream carried by the IWCS is believed to have been similar to the present-day waste stream generated by similar facilities on main Kelly AFB.

East Kelly AFB discontinued use of the East Kelly IWCS in the 1970s. In 1982, a portion of the northwestern corner of East Kelly was transferred to St. Philips College, including Buildings 3004, 3008, and 3020. This transfer included the southern leg of the IWCS line connecting the facilities. St. Philips College uses Building 3004 as an administrative office, Building 3008 for vocational teaching of aircraft body work, and Building 3020 for vocational teaching of engine repair. In the late 1980s, St. Philips College renovated Building 3020; this renovation included modifying the stormwater lines located near the IWCS. This revealed several cross-connections between the stormwater system and the IWCS. These cross-connections were confirmed by a video inspection in 1998. Smoke testing also conducted in 1998 confirmed that the IWCS line is broken or collapsed in many locations.

A preliminary investigation of the Site SS051 IWCS was conducted as part of the Focused Feasibility Study (FFS) for SS051 (CH2M HILL, 1998). The preliminary investigation was necessary because of the uncertainty of the location and condition of the former IWCS line. The investigation included a records search and physical survey of the storm, sanitary, and IWCS lines in the vicinity of Site SS051. The records search included gathering property record data and reviewing design and as-built drawings. The physical survey included observations of accessible facilities; closed circuit television (CCTV) work within the lines, where possible, to determine the integrity of the pipe; and smoke and dye tests to determine where interconnections exist.

A record search of the property deed dated 8 February 1982, for what is now St. Phillips College, identified the presence of the IWCS line and provides easement rights to the Air Force for immediate or emergency repairs. It further states that the college will maintain, repair, and replace the lines as necessary to keep them in good working order and that no abandonment or alteration of these lines will ever be made without the written approval of the representative of the United States Government. It is unknown if the Air Force gave concurrence for the modification to the stormwater lines and IWCS as part of the renovation of Building 3020.

During review of design, construction and as-built drawings of the utility systems and facilities in the vicinity of Site SS051 it became evident that definition of the location of the IWCS lines is lacking. There is conflicting information regarding connections and locations between as-built drawings of the facilities and the utility drawings. The most reliable drawing found was a 1987 legal survey performed during the renovation of facility P3020. This renovation included upgrades to the storm drain system parallel to the IWCS line located between facilities P3020 and P3008. This survey identified several manholes and pits thought to be oil/water separators that were most likely associated with the IWCS, but which no longer exist. These were probably abandoned in place and covered by either new asphalt or fill material. The manholes and pits also appear to fall in line with what is thought to be the IWCS line that parallels the existing storm drainage system on the south side. A discussion of the integrity of the IWCS follow. Because this pipeline is blocked in several places it is assumed that St. Phillips College is not using the system.

Physical surveys of the site, storm lines and IWCS lines confirm that the IWCS line running east from building P3003, between buildings P3020 and P3008, and extending to manhole 001 has been abandoned and the integrity breached. The CCTV push camera work revealed three severe breaches in the IWCS line that allowed for construction fill material to enter and plug the line. The first breach was discovered about 29 feet west of manhole 001. This placed the breach directly beneath the new concrete curb and apron that was constructed at the north east corner of building P3020. The other two breaches were found at cross connections between the IWCS and the new storm drain at grates 001 and 002, four or five feet into the pipe.

Smoke tests performed at storm grate 001 also confirmed poor integrity of the IWCS. When smoke was introduced and forced through the cross connection towards the IWCS the only appearance of smoke was up through the ground around the concrete curb and apron.

The IWCS line leading north from manhole 002N had been intentionally plugged with a concrete cap placed in the invert within the manhole. The integrity of the line between manhole 002N and storm sewer (SS) 001 is also questionable. With the concrete plug in manhole 002N, the only access to this line was through SS 001 heading south towards manhole 002N. The CCTV revealed the line to be plugged with sludge material approximately 20 feet south of SS 001.

In total, three lengths of the IWCS were investigated; (1) the line from building P3003 to manhole 002, (2) the line from manhole 002 to manhole SS 001, and (3) the line from manhole SS 001 to the lift station north of building P3004. Of these three lengths only the third one appears to be intact. The integrity of the second length is questionable and at least known to be plugged. The first line is the most critical and appears to have been abandoned in place using no precautions to prevent contamination from entering the soil and migrating towards groundwater.

In addition, the newer storm drain line running parallel to the IWCS (between buildings P3020 and P3008) was investigated. This line has several areas that are, like most storm lines, suspected of leaking. This leakage is important to note because this could provide a source of groundwater recharge by which contaminants from the IWCS in the vadose zone are being transmitted to the groundwater.

Trichloroethene (TCE) was the primary degreasing solvent used at the base until 1973. TCE was replaced for a short time by trichloroethane (TCA). The use of TCA proved to be corrosive to metal piping and was replaced in the mid-1970s by tetrachloroethene (PCE).

Therefore, PCE was not used, at least in large quantities, in the engine repair facilities on East Kelly because by the mid-1970s the work had been moved to main Kelly

3.1.2 Site MP

Site MP is located along the eastern border of Kelly AFB within IRP Zone 3 and is surrounded by industrial buildings and offices and the Union Pacific railyard to the east. **Figure 3.3** shows the location of Site MP relative to the IRP zones established for Kelly AFB, and **Figure 3.4** is a site map showing former building locations associated with Site MP. The buildings were all demolished by 1981; Site MP is currently an asphalt parking lot.

Originally, Site MP was the site of two shop buildings constructed in 1933 for automotive maintenance. Former Building 258 was originally designed to be a quartermaster maintenance shop and warehouse. This building had large areas of space to store automotive parts. It also served as an area for various functions, such as carburetor repair, electrical maintenance, shop maintenance, and wash rack were conducted here.

Former Building 259 was designed to be a quartermaster garage and had a wash rack and hydraulic lift. The plot plan on as-built drawings indicates that the wash rack drains were connected to the sanitary sewer lines. Several other buildings were located near former Building 259, including a large underground storage tank (UST) field and fuel dispensers (SAIC, 2000).

Between August and October 1952, former building 258 was modified by the addition of a zinc plating pit (SAIC, 2000). Other modifications that were made after installation of the zinc plating pit included adding the capability for lead and chrome plating, aluminum and magnesium anodizing, as well as a capability to phosphatize and oxidize equipment in 1955 (SAIC, 2000).

Former Building 259 was modified into a plating shop in 1961. A chrome-plating line, anodizing area, and electroless nickel areas were added, and each was connected to the industrial waste (IW) line. Each work area (chrome, anodizing and nickel) had a drain line connecting to an eight-inch IW line, which in turn flowed into the 72-inch storm sewer located parallel to Berman Road (SAIC, 2000).

Figure 3.4 shows the principle components of the facilities (former Buildings 258 and 259) where solvents were managed: the propeller line degreaser, other degreasers, the drain trench and the container storage area. As stated previously, the aboveground structures of Buildings 258 and 259 were demolished in 1980 and 1981, respectively. The concrete belowground structures, including large pits used for plating propellers and other airplane parts, were left in place and backfilled with construction debris from the demolition of the metal-plating buildings. The floor slab of Building 259 was removed, but some of the below-ground structures still remain. **Figure 3.4** shows the former locations of the underground fuel tank storage area and the IWCS that were located near former Building 258. All tanks have been removed or abandoned in place, and the IWCS line was scheduled for investigation and closure in the fall of 2000.

Investigations at Site MP began when the two former metal plating shops (Buildings 258 and 259) were designated as an IRP Site (Site OT-2, later named MP). Through the investigation process, a pool of PCE DNAPL was located beneath the former Building 258.

3.2 Current Conditions

3.2.1 Hydrogeology

Figure 3.5 illustrates the stratigraphy in the vicinity of Kelly AFB. A thin layer of alluvium overlying a thick sequence of Cretaceous-age sediments characterizes the regional geological setting at Kelly AFB. Beneath the alluvium, Navarro Group clays are encountered at depths ranging from zero to 50 feet across the base and extend about 450 feet in the subsurface. The unit is underlain by more than 300 feet of the Taylor Marl, which in turn is underlain by a series of limestone and shale beds that are about 500 feet thick. The limestone and shale sequence, in order of increasing depth, consists of Anacacho Limestone, Austin Chalk, Eagle Ford Shale, Buda Limestone and Grayson Shale (Del Rio Clay), which immediately overlies the Edwards Aquifer. In the vicinity of Kelly AFB, the top of the Edwards Aquifer exists at about 1,500 feet below ground surface (bgs).

Alluvial sediments and soils are generally found within the top 30 to 50 feet of the surface at Kelly AFB. These sediments and soils are composed of clays and gravels as well as fill materials that overlie the Navarro Group. The alluvium generally consists of a fining upward sequence from coarse basal gravel to silt, clay and fill material. The fining upward sequence is attributed to depositional environments that range from a migrating, braided stream system to a meandering stream system. The basal gravel and clayey gravel lithofacies are widespread and are the most common water-bearing units.

HNUS (1989) divided the shallow stratigraphy into 11 units: two types of man-made material, eight lithofacies (defined as distinct, lateral subdivisions of a stratigraphic unit distinguished by lithology), and the Upper Navarro Group. Not all of the units occur throughout Kelly AFB, and other formations (the Midway Group) encountered in Zone 4 were not included in the HNUSs lithofacies list. Lateral and vertical discontinuities in these lithofacies are common.

The black clay is an organic-rich clay with variable amounts of gravel and trace amounts of silt, caliche and fine sand. It grades into the brown clay, which is distinguished by more caliche nodules, silt and sand, as well as occasional thin gravel stringers. The silt and sand beds, which may also contain some clay, silt and gravel are not as laterally extensive as the other lithofacies. A thin sand and gravel unit sometimes overlies the Navarro Group directly and, if present, is the most transmissive water-bearing unit.

The clayey gravel and gravel beds are gradational and are distinguished by the amount of clay and silt material. Grain clast sizes range from coarse sand to medium cobbles. It is probable that boulders occur in the gravel beds.

A lower clay unit occurs predominantly on the east side of the base just above or below the gravel unit. The lower clay unit is more plastic and compacted than the black and brown clays. A Navarro Clay transition zone is a thin zone of intermixed alluvium and Navarro-like clay that has been encountered in some of the borings.

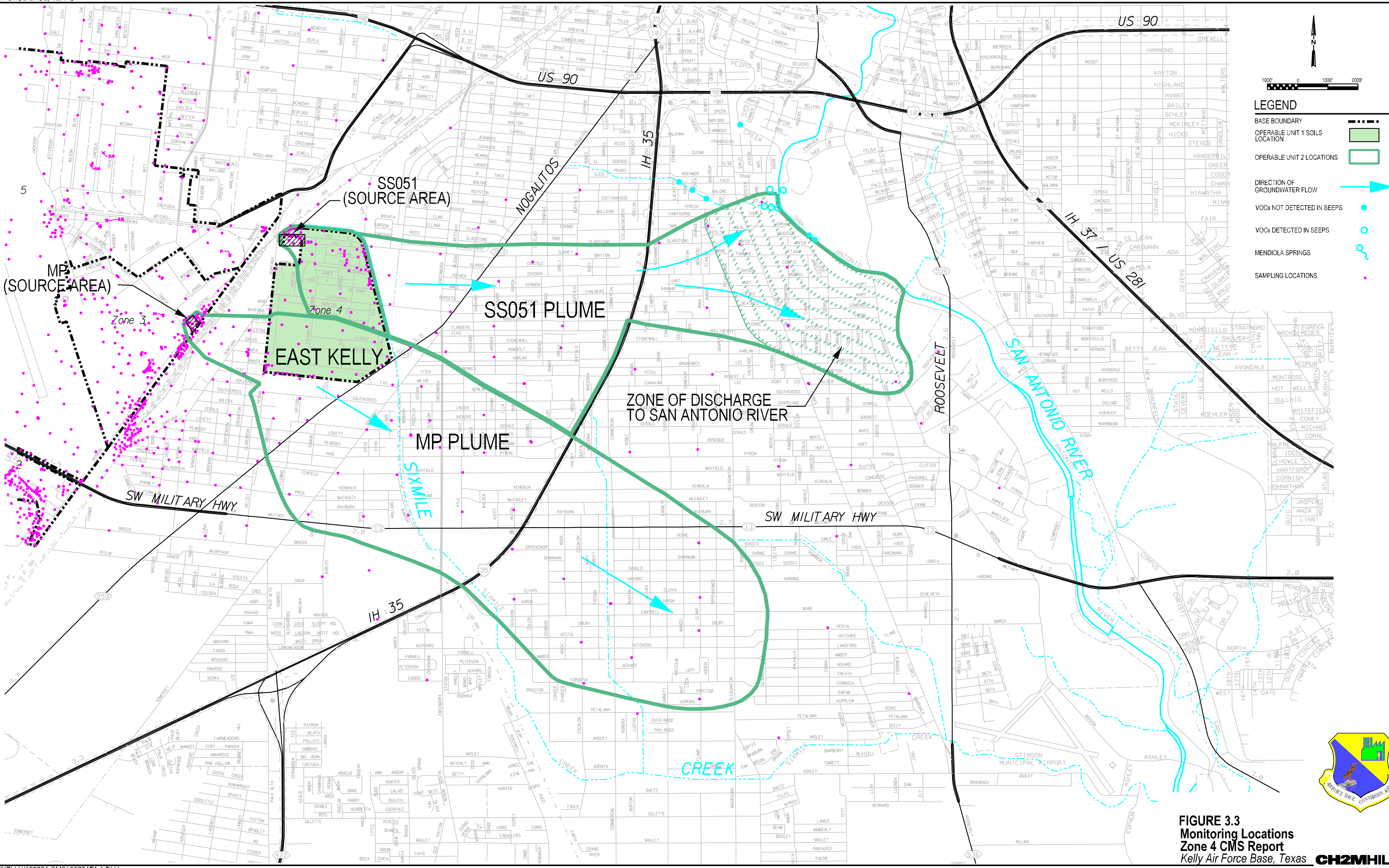


FIGURE 3.3
Monitoring Locations
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

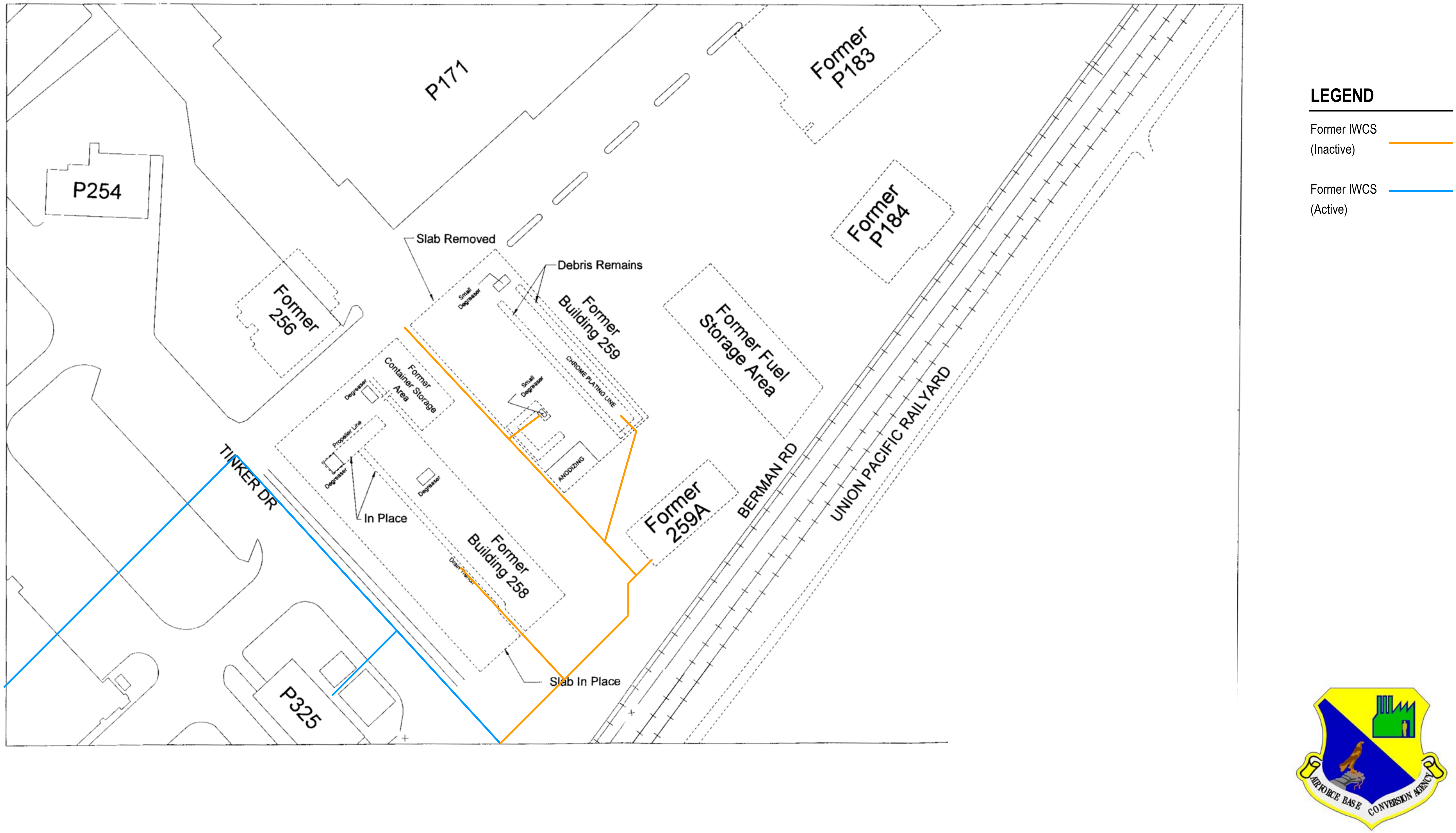


FIGURE 3.4
Former Building Locations at Site MP
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

FIGURE 3.5
Stratigraphy in the Vicinity of Kelly AFB
Kelly AFB, San Antonio, Texas

System	Series	Formation		Description	Depth (bls)
Tertiary	Recent	Alluvium (20')		**Clay**: Yellow with gravel.	
	Paleocene	Midway Group (0-100')		**Shaley Clay**: Sandy, silty, jointed and oxidized to 75 ft; secondary gypsum associated with jointing; bentonitic, high plasticity; gray weathers tan.	100'
				Clay: With glaucontic sand and silts. **Bentonite:** 2 ft thick.	
Cretaceous	Gulf	Navarro Group (450')		**Shaley Clay**: Sandy and silty with limestone concretions throughout; gray weathers tan. The Gas Ridge Oil Field, which was discovered in 1912 and is located just south of Lackland AFB, produces oil from thin sand lenses in the lower 300 ft of the Navarro Group.	200' 300' 400' 500' 600'
		Taylor Marl (315')		**Marl and Calcareous Shale**: Fossiliferous, blueish-gray.	700' 800' 900'
		Anacacho Limestone (212')		**Argillaceous Limestone and Marl**: Fossiliferous, gray. Natural gas was produced from the Anacacho Limestone in the Gas Ridge Field south of Lackland AFB.	1,000' 1,100'
		Austin Chalk (106')		**Limestone**: Soft argillaceous, fossiliferous, gray.	1,200' 1,300'
		Eagle Ford Shale (36')		**Flaggy Calcareous and Sandy Shales**: Interbedded with more argillaceous limestone, dark gray.	
	Comanche	Buda Limestone (61')		**Limestone**: Fine-grained, dense, hard, gray.	1,400'
		Grayson Shale (Del Rio Clay) (65')		**Clay**: Soft, fossiliferous, pyrite and gypsum throughout.	
		Edwards and Associated Limestone		**Georgetown Member Limestone**: Hard, massive.	1,500'

Source: McIntosh & Behm (1967)
Engineering Science, Inc. (1982)
NUS Corp. (January 1990)

bls below land surface

CH2MHILL

The laterally extensive Navarro Clay is a mottled, orange-brown, blue-gray to green-gray, stiff plastic clay with silty partings. Some fine sand layers are present, and caliche may be present in the upper six feet. Lithified beds of sandstone have been observed in Navarro outcrops along the San Antonio River. The sandstone is gray to white, discontinuous and rarely more than a few inches thick.

Caliche, a diagenetic calcium carbonate cement, is found as nodules or thin coatings on gravel in the alluvium. In some cases, particularly in borings drilled above local highs in the Navarro Group surface, sections of calichified clay, silt, and gravel were found (HNUS, 1989). The presence of calichified material may be significant hydrogeologically because caliche can impede groundwater flow.

Groundwater is often, but not always, present in the basal sand and gravel layer. These saturated coarse-grained beds form the uppermost aquifer-zone that is referred to as the alluvial aquifer-zone. At some locations the uppermost aquifer-zone is unconfined; however, at other locations the potentiometric surface is up to 25 feet above the top of the aquifer-zone (CH2M HILL, 2001). This uppermost aquifer-zone is the unit affected by releases from Site SS051 and Site MP.

The alluvium overlies about 450 feet of combined thickness of the Navarro Group and Taylor Marl (Upper Cretaceous) over most of Kelly AFB. These formations are fine-grained and do not yield water to wells. The Geologic Atlas of Texas, San Antonio Sheet (BEG, 1983) describes the Navarro and Midway Groups as largely composed of clay with minor components of silt and sand with colors ranging from yellow to olive-green. Both of these geologic units create an effective barrier to the downward flow of groundwater due to the predominance of clay and silt. The base of the alluvial aquifer-zone is the Navarro/Midway Surface.

The surface topography of the Navarro/Midway is an important control on the distribution of alluvial sediments and occurrence of preferential flow paths in the alluvial aquifer-zone. **Figure 3.6** shows the topography of the Navarro/Midway and indicates a general east-to-southeast slope.

In general, the potentiometric surface of the surficial aquifer-zone mimics the surface of the Navarro/Midway, and groundwater flow directions are generally to the east and southeast across most of the area of interest. The direction of groundwater flow may vary as a result of changes in the distribution and permeability of the alluvial sediments.

Hydraulic gradients were evaluated using water level data gathered in September 2000 (CH2M HILL, 2000c). Compared to historical gradients, the most recent data indicates that hydraulic gradients do not significantly vary over time. The gradient across OU-2 ranges from 0.001 to 0.002 feet per foot (ft/ft). The highest gradient occurs in the northern part of East Kelly where the alluvial aquifer-zone is relatively thin. The lowest gradient occurs in the center of East Kelly where coalescing relic channels are evident on the Navarro/Midway surface. Along these channels, thicker and more permeable deposits of alluvial sediments occur, resulting in a lower hydraulic gradient.

Groundwater flow rates are highly site-specific because of the variability in thickness and permeability of the aquifer-zone. Where the aquifer-zone materials are thin and have low permeability the flow rates will be less than one foot per year. Conversely, in the more permeable aquifer-zone sections, flow may be up to 10 feet per day (f/d). Average flow rates over large distances in the preferential flow paths are estimated to range from one to three f/d.

3.2.2 Nature of Contamination

As part of the Zone 4 RFI, all groundwater analytical data from 1994 to 1999 was evaluated to develop an understanding of the nature of contamination in groundwater affected by operations at Kelly AFB. The result of those detailed evaluations was to determine whether corrective action is required and, if required, to develop a list of chemicals to be addressed by those corrective actions.

Chemicals to be addressed by corrective actions were identified based on comparison of chemical concentrations in groundwater to TNRCC Risk Reduction Standard No. 2 (RRS 2) medium-specific concentrations (MSCs). Specifically, values are groundwater MSCs for residential (GW-Res) and industrial (GW-Ind) use as presented in the most recent update of TNRCC RRS 2 Appendix II Medium-Specific Concentrations (March 15, 2001).

Based on the potential for the discharge of contaminated groundwater from Site SS051 to impact the state surface water bodies of San Pedro and Concepcion Creeks and the San Antonio River, applicable surface water quality standards from Section 30, Chapter 307 of the Texas Administrative Code (TAC) were also considered during the evaluation of Zone 4 OU-2 RFI groundwater impacts.

The following summarizes the list of chemicals that were found at levels exceeding the applicable criteria for IRP Sites SS051 and MP.

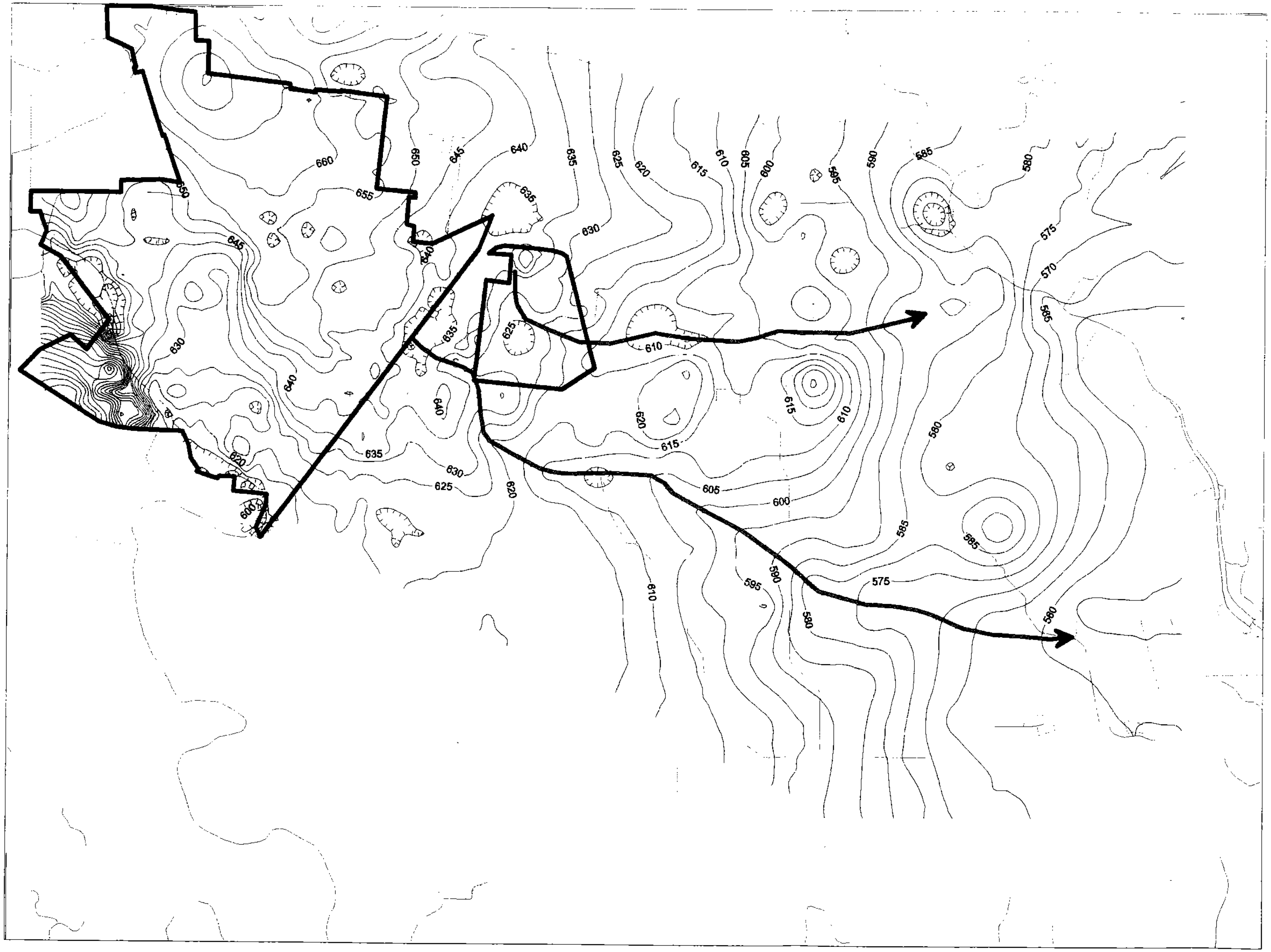
3.2.2.1 Site SS051

For Site SS051, those chemical parameters exceeding their respective MSC are shown in **Table 3.1,** along with the historical maximum detected concentration. This table shows that TCE and 1,2-dichloroethene (DCE) are the predominant contaminants of concern (COCs) at site SS051.

TABLE 3.1
Historical Frequency of Detection of Contaminants of Concern in Site SS051 Source Wells
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Parameter	Number of Analyses	Number of Detects	Maximum Detected Concentration (µg/L)
Total chromium	14	9	114
Tetrachloroethene	16	1	2
Total 1,2-dichloroethene*	15	6	1,200
Trichloroethene	16	14	790
Vinyl chloride	16	1	24

µg/L micrograms per liter
* predominantly cis-1,2 DCE



0(ft.) 10,000(ft.) 20,000(ft.)

LEGEND

Elevation contour in feet above National Geodetic Vertical Datum. Hatched contour lines represent a closed decrease in elevation (depressi

Kelly AFB boundary

Primary flowpaths based upon Navarro/Midway Group topography

FIGURE 3.6
Navarro/Midway Surface Topography
Zone 4 CMS Report
Kelly AFB, Texas

3.2.2.2 Site MP

For Site MP, those chemical parameters exceeding their respective MSCs are shown in **Table 3.2,** and the historical maximum detected concentration.

TABLE 3.2
Historical Frequency of Detection of Contaminants of Concern in the Site MP Source Wells
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Parameter	Number of Analyses	Number of Detects	Maximum Detected Concentration (μg/L)
Arsenic	17	8	91
Benzene	38	15	85
Total chromium	4	2	14
Tetrachloroethene	35	33	200,000
Total 1,2-dichloroethene*	25	24	13,000
Trichloroethene	38	35	67,000
Vinyl chloride	39	22	610

μg/L milligrams per liter
* predominantly cis-1,2 DCE

3.2.3 Extent of Contamination

This section summarizes the vertical and lateral extent of contamination for the chemicals found to exceed TNRCC RRS 2 criteria. The discussion describes the extent of contamination at the two source areas (Site SS051 and Site MP), as well as in downgradient plumes emanating from the sources.

3.2.3.1 Vertical Extent

The vertical extent of contamination in both the Site SS051 and Site MP groundwater plumes is limited by the low permeability beds at the top of the Navarro and Midway Formations. The vertical permeability of the Navarro and Midway Clays is four to six orders of magnitude lower than the horizontal permeability of the basal sand and gravel of the alluvium. Therefore, groundwater within the alluvium flows laterally and does not penetrate the Navarro/Midway.

3.2.3.2 Site SS051: Contaminants of Concern with Limited Extent

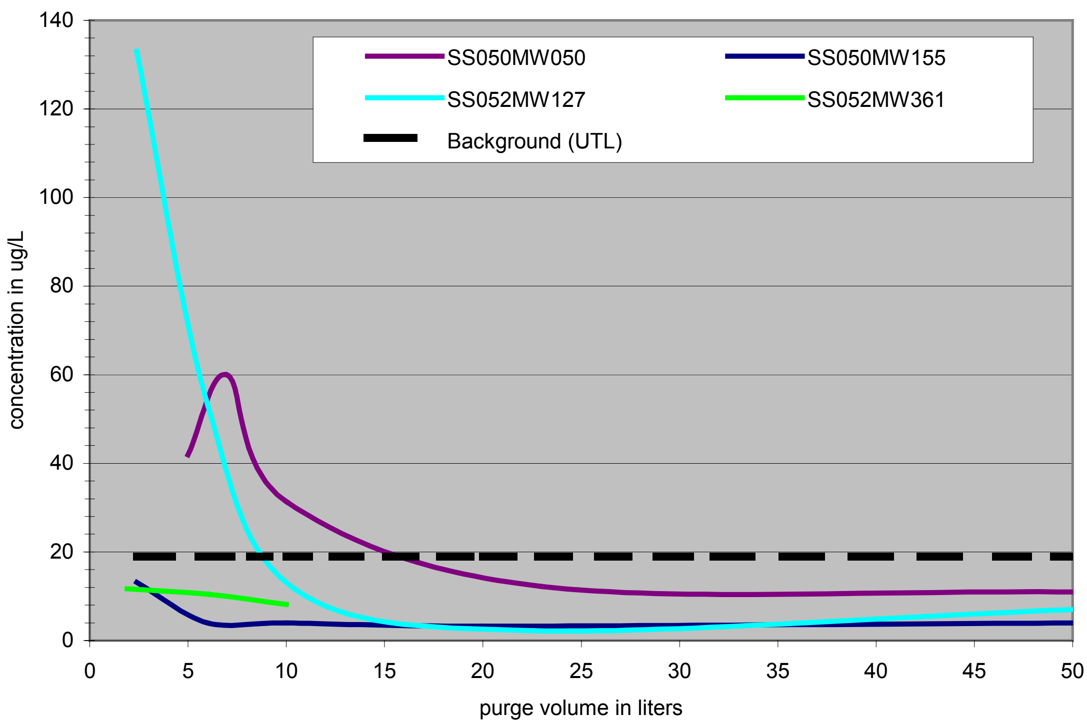
Within the Site SS051 source area, chromium was detected in only one of four samples collected during the 1999 Semiannual Compliance Plan (SACP) sampling event. This detection, 22 μg/L, is well below the TNRCC RRS 2 GW-Res and GW-Ind value of 100 μg/L.

In the Site SS051 plume area, only two exceedances of the TNRCC regulatory value for total chromium (100 μg/L) were noted in the 1999 SACP results; both occur outside the East Kelly boundary. Monitoring well SS052MW198 is located north of East Kelly (**Figure 3.7**) and had chromium at a concentration of 413 μg/L. Because this well does not lie on a direct flow path downgradient of Site SS051, this exceedance is not likely the result of a Kelly AFB release.

Well SS052MW182 is located about 4,500 feet downgradient of Site SS051 outside the eastern boundary of East Kelly (**Figure 3.7**) and had chromium concentration of 226 µg/L. This well is separated from the source area by several wells that do not have detectable concentrations of chromium.

A nickel-chromium study was performed as part of the 2001 Compliance Plan project. The purpose of the study was to evaluate the likelihood of interference in the metals analyses of groundwater samples from stainless steel used in the construction of the wells. The effort consisted of collecting time-series groundwater samples using the micropurge method and continuing the purge through a total volume of 50 liters. The composition of No. 304 stainless steel includes 19 percent chromium, nine percent nickel and two percent manganese. The plot below shows the change in chromium concentration during the extended purging.

Chromium Trends from Nickel-Chromium Study



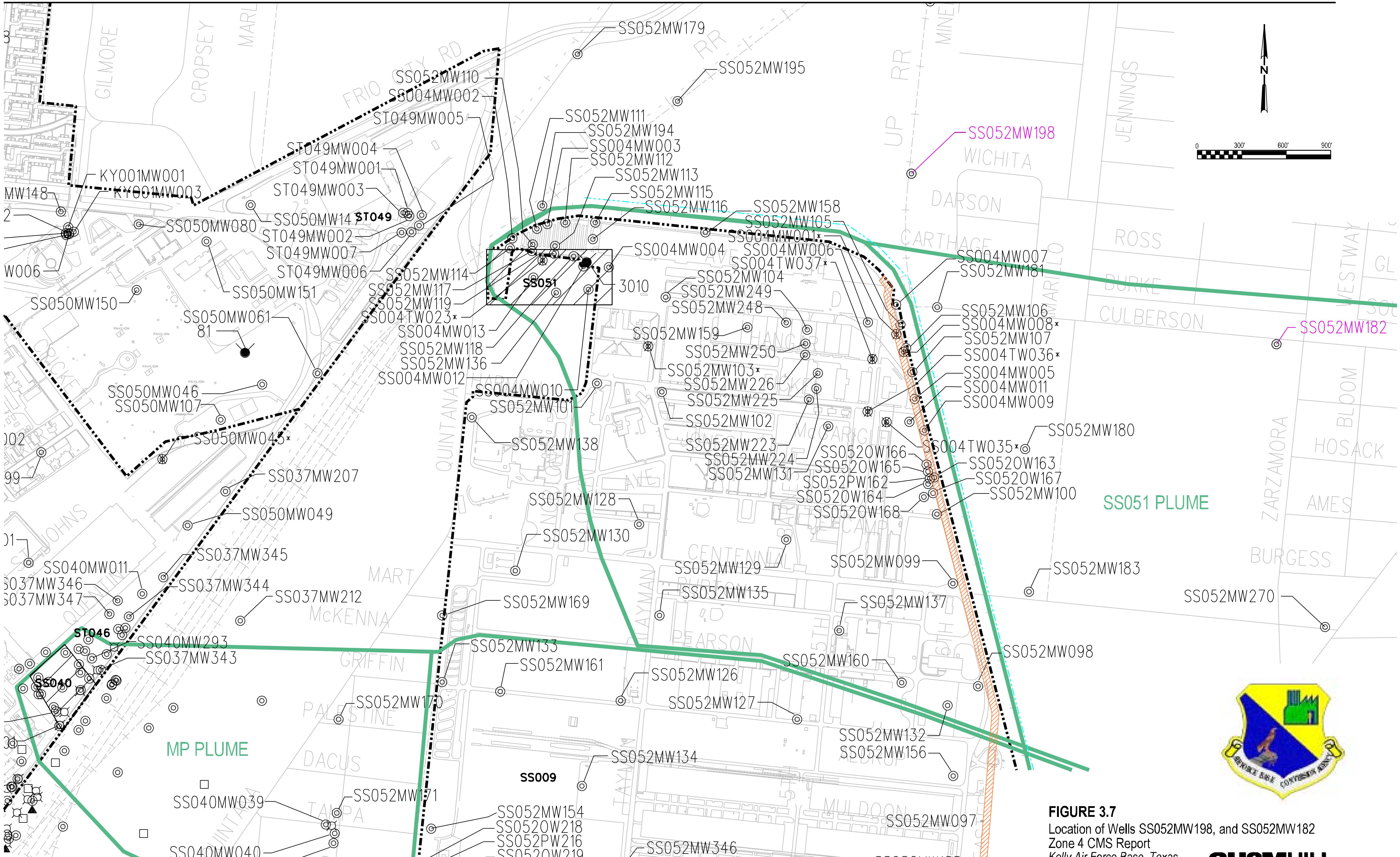


FIGURE 3.7
Location of Wells SS052MW198, and SS052MW182
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

The nickel-chromium study shows that under the current micropurge protocol of one to three liters is likely to overestimate the steady-state concentrations. In the most extreme case shown above, the initial concentration was 20 times the final conentration. The conclusion drawn from this study was that the minute corrosion of the stainless steel casing contributes small quantities of chromium to the water column and that the micropurge method overestimates the true concentrations in the aquifer.

The isolated detections of chromium are not likely from the SS051 source due to the lack of correlation between the occurrence of the chlorinated VOCs and the chromium plus the likelihood that the chromium is an artifact of the stainless steel well materials.

3.2.3.3 Site SS051: Chlorinated Volatile Organic Compounds

Groundwater data indicate that Site SS051 appears to have been the historical source of groundwater contamination that stretches from the site eastward to the San Antonio River. As described further below, the dominant chemicals in this plume are TCE and its daughter product cis-1,2-DCE.

3.2.3.4 PCE

The extent of PCE contamination is shown in **Figure 3.8**. PCE is detected infrequently in the on-base part of the Site SS051 plume. PCE was detected at a maximum concentration within the plume boundaries at 61 μg/L in MW SS052MW159 in 1999, located in the northern portion of East Kelly within the DRMO area, not Site SS051. Monitoring well SS052MW159 PCE concentration decreased to 1.6 μg/L in 2001. This well has had consistent detects of PCE. The PCE being sourced somewhere in the DRMO area commingles with the TCE/1,2-DCE plume that was sourced at Site SS051. Concentrations of PCE drop to levels below 1 μg/L in the off-site wells closest to the eastern boundary of Zone 4 indicating that the PCE detected on East Kelly does not migrate beyond the boundaries at concentrations greater than the MSC. PCE concentrations increase to levels above the MSC at a distance of about 2,500 feet east of the East Kelly boundary. The increase in concentration of PCE is from off-site sources located north of east Kelly.

Industrial land to the north of East Kelly is the likely location of the off-site source; however, there are insufficient data to pinpoint a release site. Concentrations also show that the PCE detected at Site SS051 is not contiguous with the detections north of the site, further indicating an off-site source of PCE groundwater contamination.

3.2.3.5 TCE

The extent of TCE contamination is shown in **Figure 3.9**. The maximum concentration in 1999 of TCE, 320 μg/L, was detected in monitoring well SS004MW010 in the northwestern portion of East Kelly at the SS051 source. Monitoring well SS004MW010 TCE concentration decreased to 140 μg/L in 2001. This well has historically been the location of the highest concentrations of TCE on East Kelly.

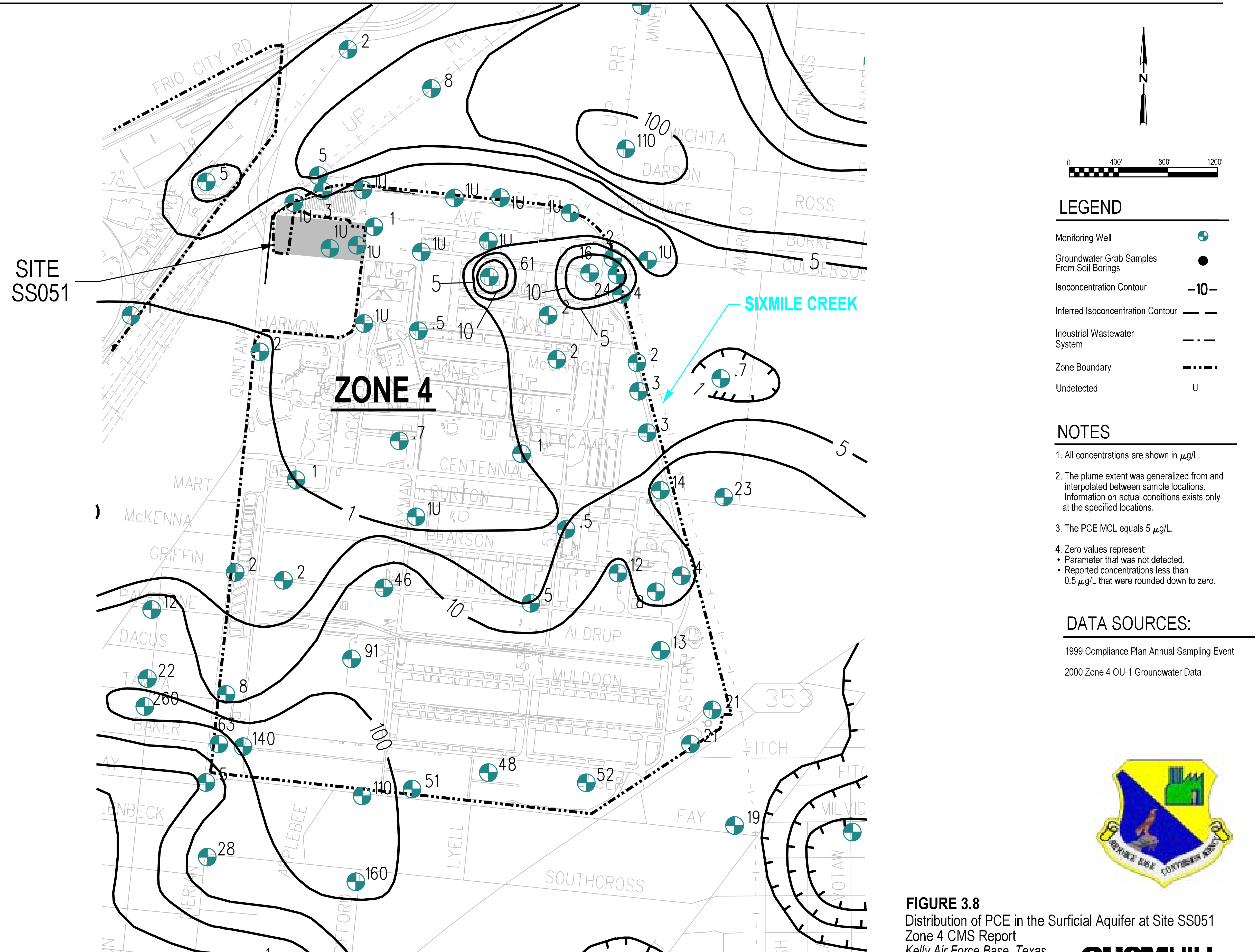


FIGURE 3.8
Distribution of PCE in the Surficial Aquifer at Site SS051
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

Although Site SS051 appears to have been the historical source of TCE contamination, soil analytical results indicate that it is not an ongoing source of groundwater contamination. The industrial solvents found in the groundwater were found infrequently in the soil, and the concentrations were within the groundwater protection standards established by the Risk Reduction Rules.

Regarding TCE concentrations observed to the north of East Kelly, RFI findings indicate this TCE is most likely from off-base sources.

3.2.3.6 Cis-1,2-DCE

The extent of cis-1,2-DCE contamination is shown in **Figure 3.10**. The maximum concentration in 1999 of total 1,2-DCE, 790 μg/L, occurred in MW SS004MW010 in the northwest portion of East Kelly. Monitoring well SS004MW010 DCE concentration decreased to 310 μg/L in 2001. This detection of cis-1,2-DCE represents the only exceedance of the TNRCC RRS 2 GW-Res and GW-Ind values in the Site SS051 source area. This well has historically contained the highest concentrations of total 1,2-DCE on East Kelly.

The extent of cis-1,2-DCE above the groundwater standard is limited to the area immediately surrounding MW SS004MW010. Other detections of cis-1,2-DCE occur across East Kelly and off-base to the east but are at concentrations significantly lower than the GW-Res and GW-Ind criteria.

3.2.3.7 Vinyl Chloride

The extent of vinyl chloride contamination is shown in **Figure 3.11**. The maximum concentration in 1999 of vinyl chloride, 12 μg/L, occurred in MW SS004MW010 in the northwest portion of East Kelly. Monitoring well SS004MW010 VC concentration decreased to non-detect in 2001. This detection of vinyl chloride represents the only exceedance of the TNRCC RRS 2 GW-Res and GW-Ind values in the Site SS051 source area.

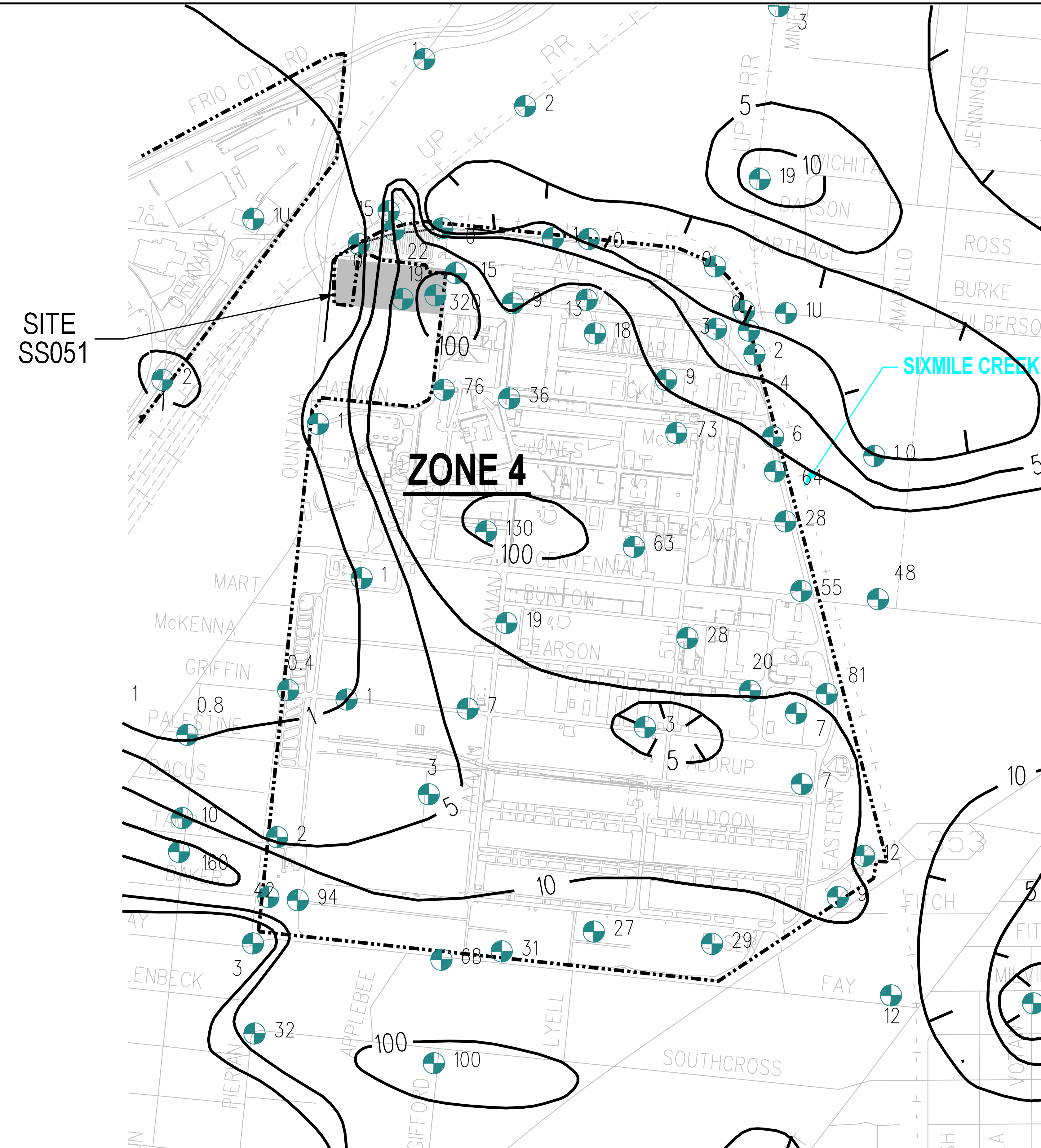
This well has historically contained the highest concentrations of vinyl chloride at Site SS051.

The extent of vinyl chloride above the groundwater standard is limited to the area immediately surrounding well SS004MW010. Other detections of vinyl chloride occur across East Kelly and offbase to the east but at concentrations significantly lower than the GW-Res and GW-Ind criteria.

3.2.3.8 Site MP: Contaminants of Concern with Limited Extent

COCs with limited extent at Site MP include arsenic, chromium, and benzene. Arsenic is limited in extent and occurs at one location within the source area. The occurrence of benzene above TNRCC RRS criteria is similar to arsenic in that it is limited in extent.

Chromium is not widespread across Kelly AFB but rather occurs in small isolated areas (**Figure 3.7**). The maximum detected concentration of chromium was observed about two miles downgradient of Site MP. Isolated detections of chromium have also been related to interference from stainless steel well materials. The distance from Site MP, coupled with the lack of detectable concentrations of chromium between this downgradient location and Site



N

0 400' 800' 1200'

LEGEND

Monitoring Well	
Groundwater Grab Samples From Soil Borings	●
Isoconcentration Contour	–10–
Inferred Isoconcentration Contour	— —
Industrial Wastewater System	—·—
Zone Boundary	–··–··–
Undetected	U

NOTES

1. All concentrations are shown in $\mu g/L$.
2. The plume extent was generalized from and interpolated between sample locations. Information on actual conditions exists only at the specified locations.
3. The TCE MCL equals 5 $\mu g/L$.
4. Zero values represent:
   - Parameter that was not detected.
   - Reported concentrations less than 0.5 $\mu g/L$ that were rounded down to zero.

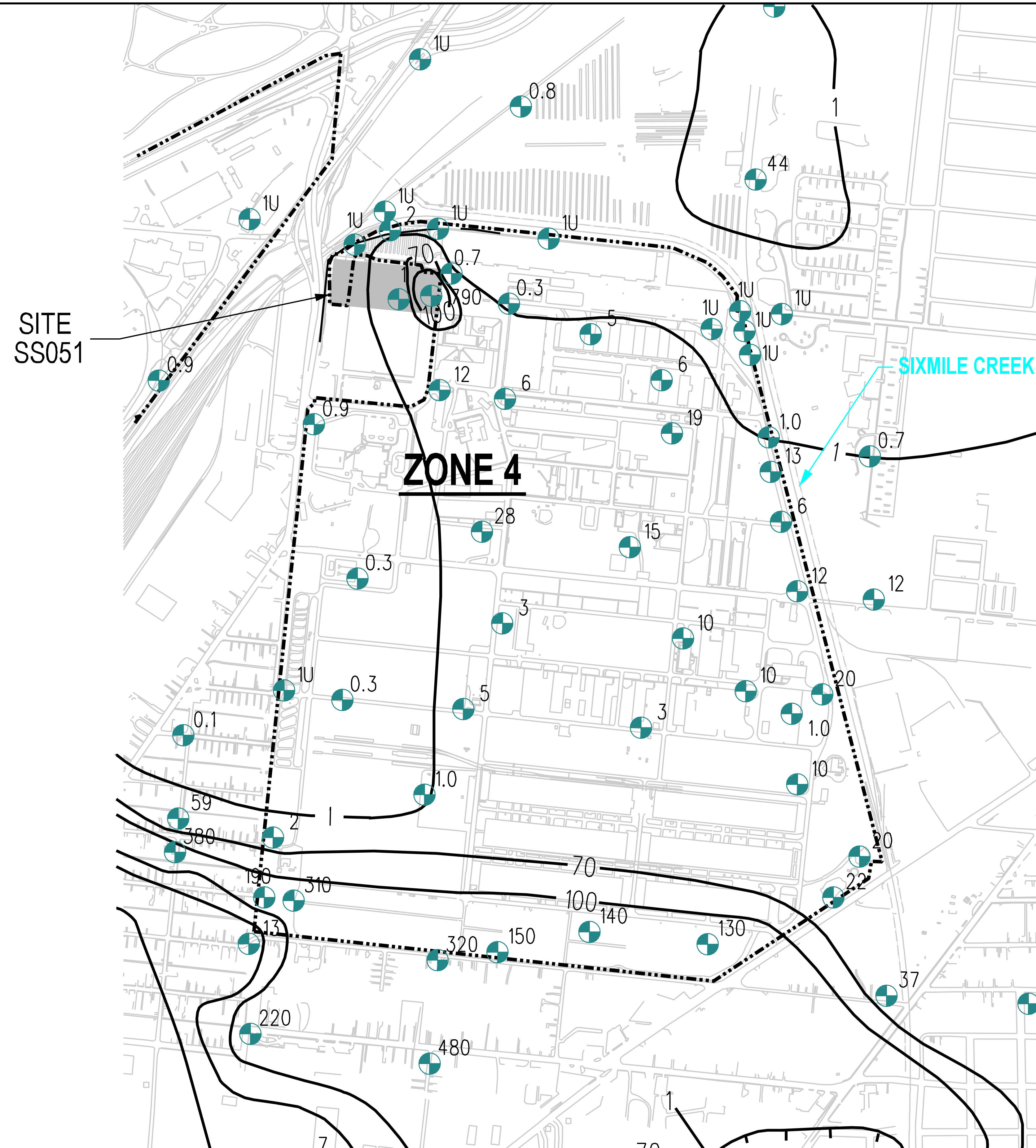
DATA SOURCES:

1999 Compliance Plan Annual Sampling Event

2000 Zone 4 OU-1 Groundwater Data

FIGURE 3.9
Distribution of TCE in the Surficial Aquifer at Site SS051
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL



N

0 400' 800' 1200'

LEGEND

- Monitoring Well
- Groundwater Grab Samples From Soil Borings
- Isoconcentration Contour –10–
- Inferred Isoconcentration Contour
- Industrial Wastewater System
- Zone Boundary
- Undetected U

NOTES

1. All concentrations are shown in μg/L.
2. The plume extent was generalized from and interpolated between sample locations. Information on actual conditions exists only at the specified locations.
3. The DCE MCL equals 70 μg/L.
4. Zero values represent:
   - Parameter that was not detected.
   - Reported concentrations less than 0.5 μg/L that were rounded down to zero.

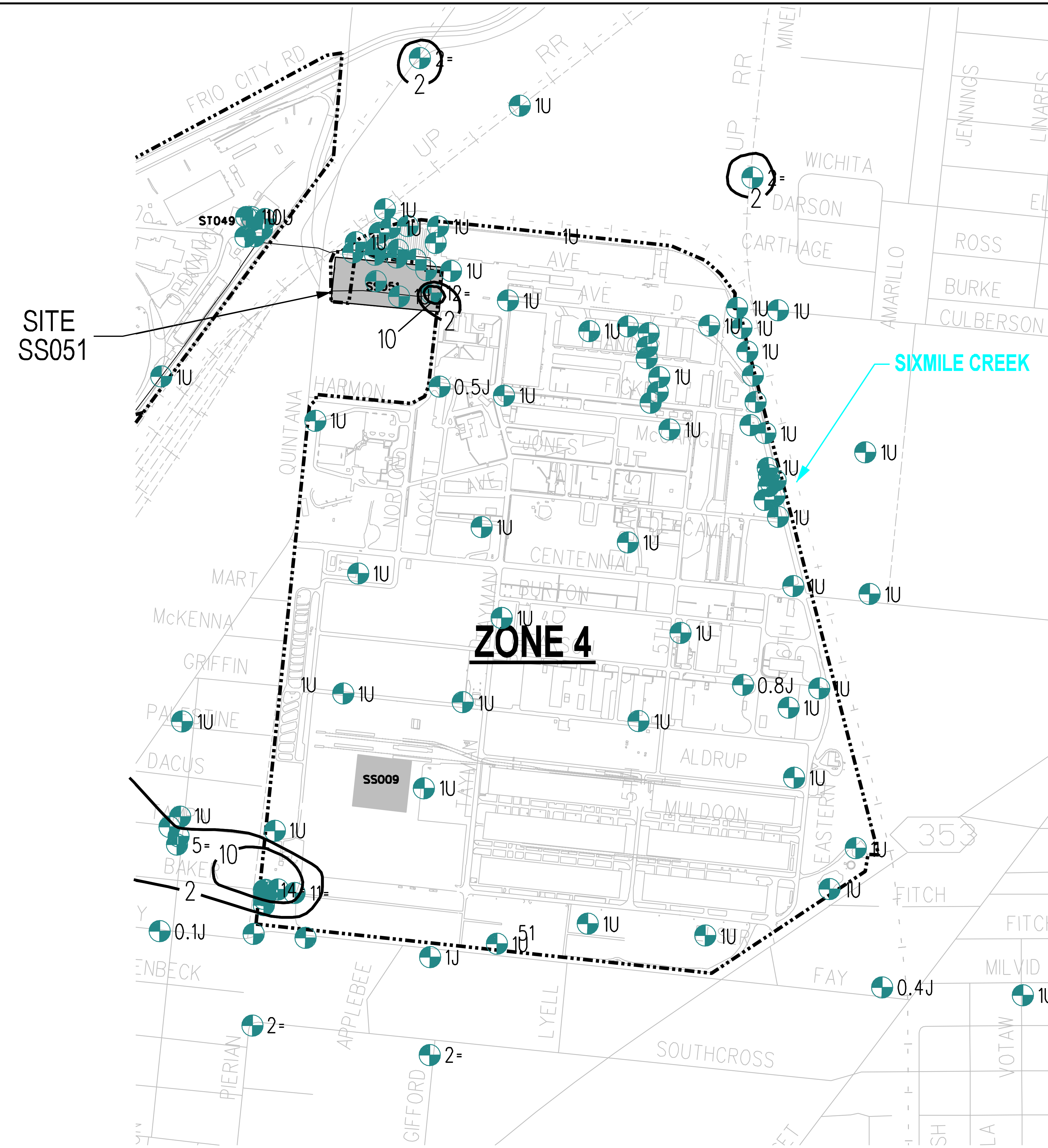
DATA SOURCES:

1999 Compliance Plan Annual Sampling Event

2000 Zone 4 OU-1 Groundwater Data

FIGURE 3.10
Distribution of DCE in the Surficial Aquifer at Site SS051
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL



N

0 400' 800' 1200'

LEGEND

Monitoring Well	
Isoconcentration Contour	— 10 —
Inferred Isoconcentration Contour	- - - -
Measured Value	.
Estimated Value	J
Undetected	U
Closed Reduction in Concentration	
Industrial Wastewater System	
Zone Boundary	
Areas of suspected or potential areas for surface and shallow subsurface soil contamination. (0-6' BLS)	WMS 10

NOTES

1. All concentrations are shown in $\mu g/L$.
2. The plume extent was generalized from and interpolated between sample locations. Information on actual conditions exists only at the specified locations.
3. All samples were collected in April/June 1999.
4. The Vinyl Chloride MCL equals 2 $\mu g/L$.

DATA SOURCES

1999 Compliance Plan Annual Sampling Event

2000 Zone 4 OU-1 Groundwater Data

FIGURE 3.11
Distribution of Vinyl Chloride in the Surficial Aquifer at Site SS051
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

MP and likely interference from well casing materials, suggests that off-base chromium is probably not related to the solvent release at Site MP.

3.2.3.9 Site MP: Chlorinated Volatile Organic Compounds

Groundwater data indicate that Site MP is the source of affected groundwater that extends from the site southeast for about 4.5 miles. The principal contaminant source at Site MP is a pool of DNAPL (mainly PCE) that occupies a depression in the surface of the Navarro Clay at a depth of about 40 feet bgs.

3.2.3.10 PCE

The extent of PCE at Site MP is illustrated in **Figure 3.12**. These contours were generated using June 1999 sampling data. Analytical data from samples collected within the slurry wall are not presented because they are hydraulically isolated from the remainder of the plume and will be addressed in a separate CMS.

The maximum concentration of PCE in 1999, 1100 µg/L, was detected in MW SS037MW203, which is located just downgradient of the source area and outside of a slurry wall that was constructed as source containment. Monitoring well SS037MW203 PCE concentration decreased to non-detect in 2001. Groundwater sample locations and concentrations of PCE outside of the slurry wall can be seen in **Figure 3.12**. These contours were generated using June 1999 sampling data. As can be seen from the contours, there is an area to the north and east of the slurry wall and areas off-site that have elevated PCE concentrations.

It should also be noted that the magnitude of PCE concentrations downgradient of the slurry wall around the Site MP source area have decreased since the 1999 SACP groundwater sampling (CH2M HILL, 2000). Table 3.3 compares of chlorinated solvent concentrations from 1998 and 1999 in seven wells located outside of the slurry wall. This indicates that the slurry wall in conjunction with the optimized recovery system is having positive effects on preventing further off-base migration of chlorinated volatile organic compounds (CVOCs).

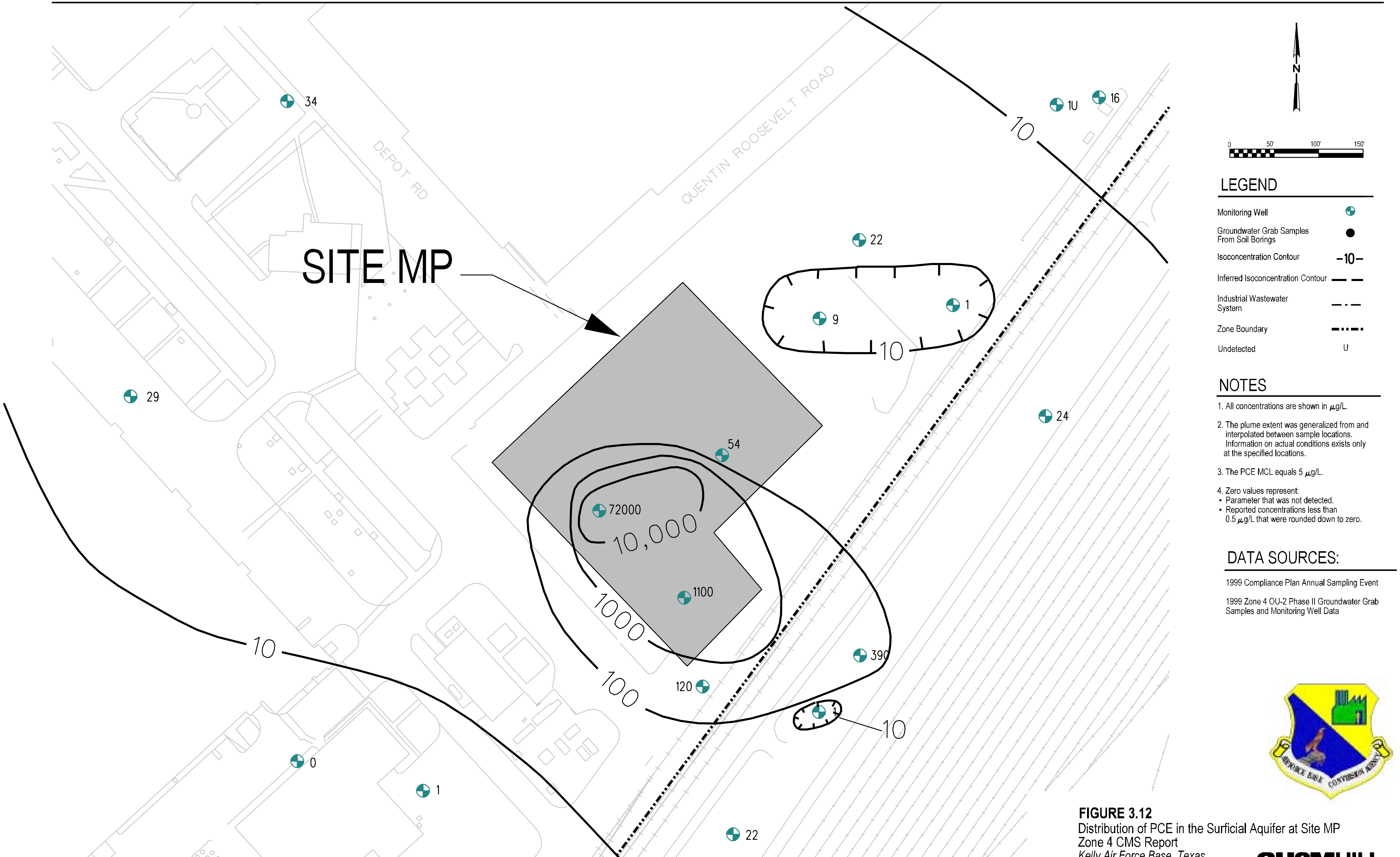


FIGURE 3.12
Distribution of PCE in the Surficial Aquifer at Site MP
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

TABLE 3.3
Solvent Data for Selected Site MP Monitoring Wells
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Well	Total Solvents [1](µg/L) March 1998[2,3]	Total Solvents (µg/L) October 1999	Total Solvents (µg/L) April 2000	Total Solvents (µg/L) April 2001
SS037MW027	5600	2250	192	3.2
SS037MW220	2520	34	13.8	8.1
SS037MW033	2729	69	39.3	11.0
SS037MW038	133	96	ND[4]	NS[5]
SS040MW001	3800	154	ND	27.2
SS040MW016	2497	269	56.7	18.9
SS040MW013	270	ND	ND	NS

Notes:
1 µg/L=micrograms per liter
2 Concentrations are for sampling during the month indicated. If no sampling was done, concentration represents the most recent previous sampling event to the date indicated.
3 Many wells could not be sampled because of extremely low water levels in 2000 due to extended drought conditions
4 ND indicates "not detected" for all constituents sampled.
5 NS =No Sample

3.2.3.11 TCE

The extent of TCE, near the base, is presented in **Figure 3.13**. The maximum concentration in 1999, 620 µg/L, was detected in MW SS037MW203, which is located in the source area but outside of the slurry wall. Monitoring well SS037MW2030 TCE concentration decreased to non-detect in 2001. These contours were generated using June 1999 sampling data. As can be seen from the contours, there is an area to the north and east of the slurry wall and areas offsite that have elevated TCE concentrations.

3.2.3.12 Cis-1,2-DCE

The extent of cis-1,2-DCE, near the base, is presented in **Figure 3.14**. These contours were generated using June 1999 sampling data. Monitoring well SS040MW016, located off base and about 100 feet downgradient from the source area, contained the maximum concentration in 1999 of cis-1,2-DCE, at 1200 µg/L. Cis-1,2-DCE is not as widespread at PCE and TCE. Monitoring well SS040MW016 DCE concentration decreased to 31 µg/L in 2001. Cis-1,2-DCE is probably a daughter compound derived from PCE and TCE degradation.

3.2.3.13 Vinyl Chloride

The extent of vinyl chloride, near the base, is presented in **Figure 3.15**. These contours were generated using June 1999 sampling data. The maximum concentration in 1999 of vinyl chloride, 780 µg/L, was detected in MW SS037MW027 located off base and about 100 feet downgradient from the source area. Monitoring well SS037MW027 VC concentration decreased to 1.1 µg/L in 2001.

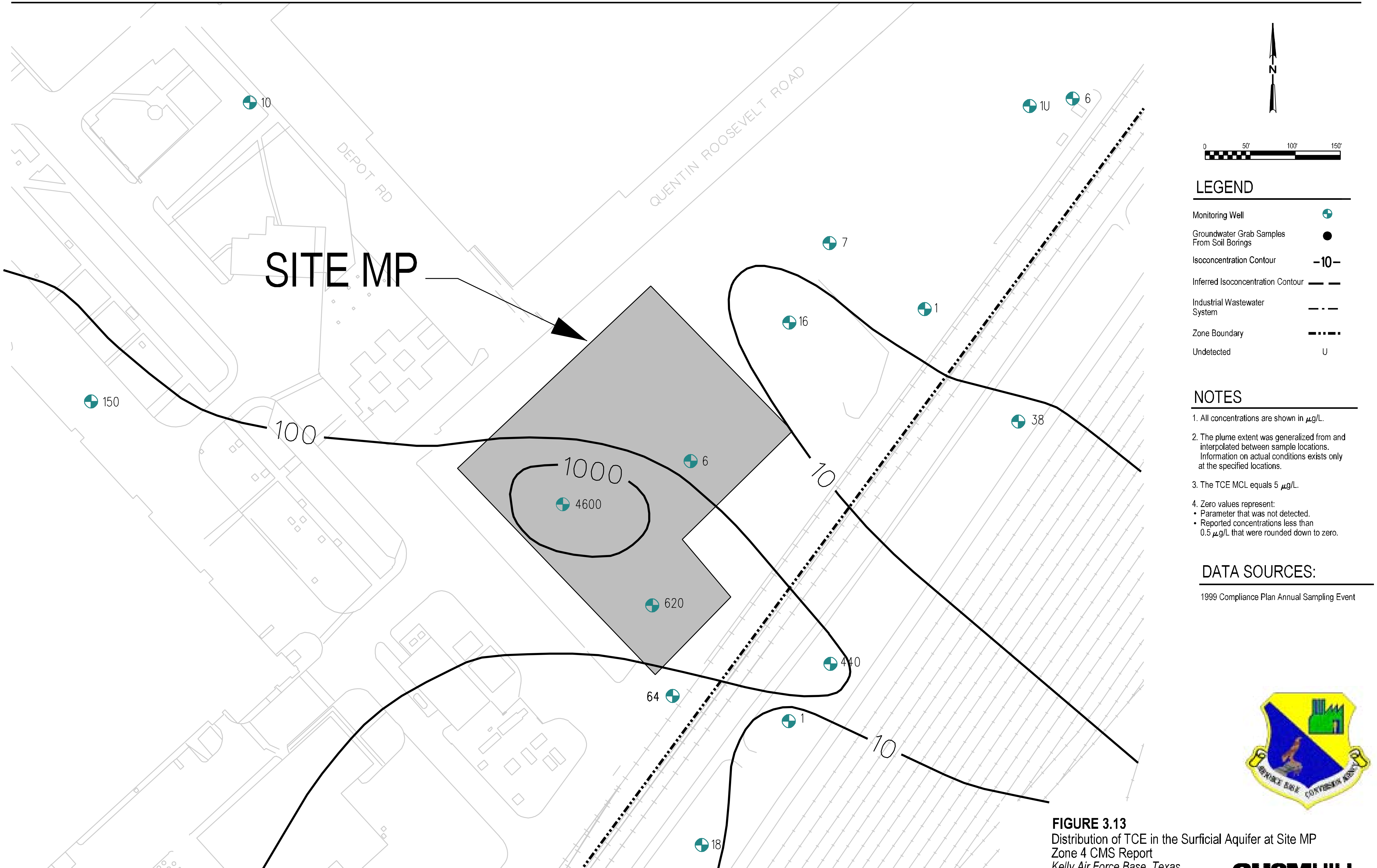


FIGURE 3.13
Distribution of TCE in the Surficial Aquifer at Site MP
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

LEGEND

Monitoring Well
Groundwater Grab Samples From Soil Borings
Isoconcentration Contour –10–
Inferred Isoconcentration Contour
Industrial Wastewater System
Zone Boundary
Undetected U

NOTES

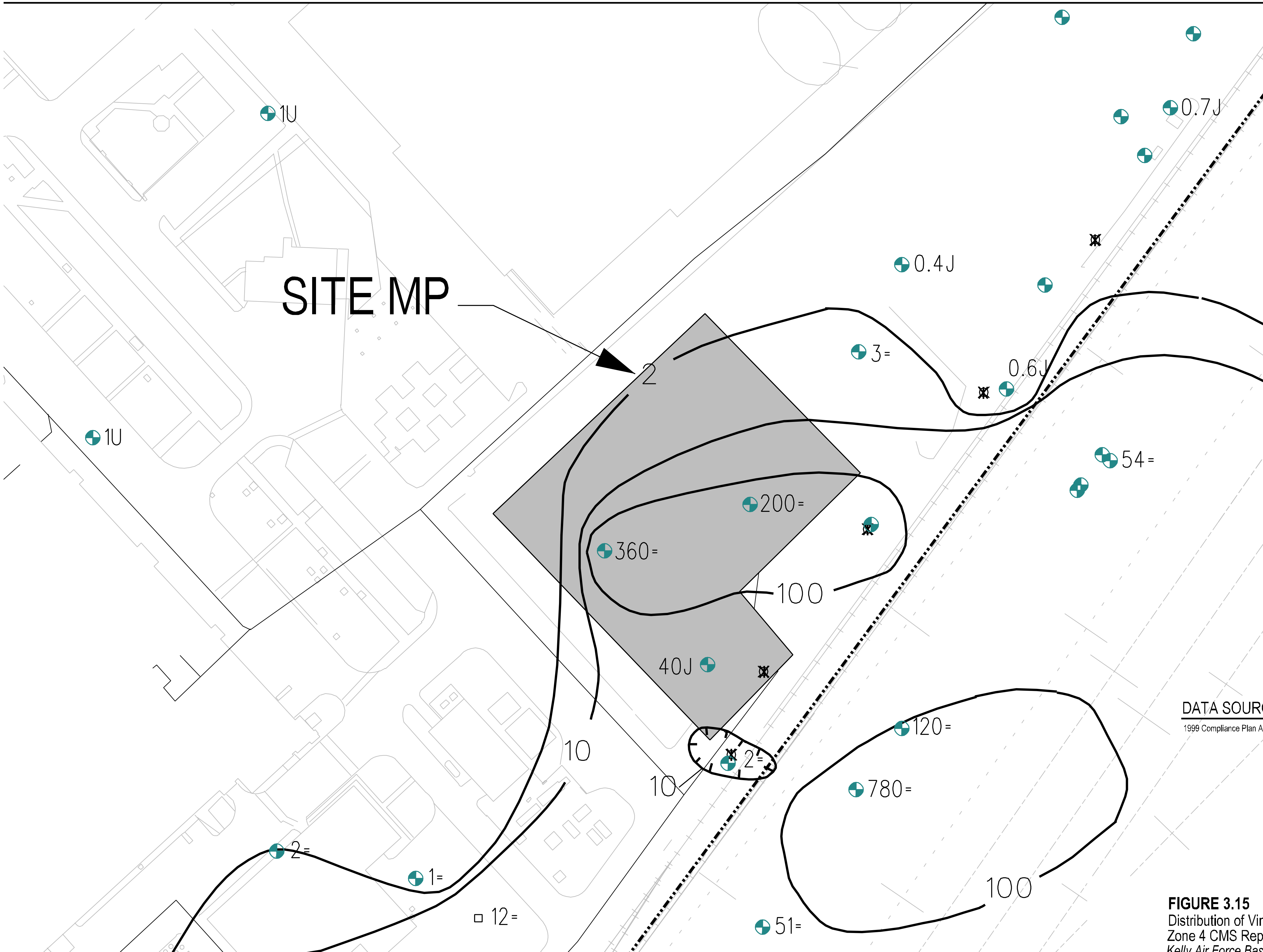
1. All concentrations are shown in μg/L.
2. The plume extent was generalized from and interpolated between sample locations. Information on actual conditions exists only at the specified locations.
3. The DCE MCL equals 70 μg/L.
4. Zero values represent:
   - Parameter that was not detected.
   - Reported concentrations less than 0.5 μg/L that were rounded down to zero.

DATA SOURCES:

1999 Compliance Plan Annual Sampling Event

FIGURE 3.14
Distribution of DCE in the Surficial Aquifer at Site MP
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL



LEGEND

Recovery Well
Monitoring Well
RCRA Monitoring Well
Abandoned Well
Operation & Maintenance Monitoring Well
Edwards Water Supply Well
Isoconcentration Contour — 10 —
Inferred Isoconcentration Contour
Measured Value
Estimated Value J
Undetected U
Closed Reduction in Concentration
Industrial Wastewater System
Zone Boundary
Areas of suspected or potential areas for surface and shallow subsurface soil contamination. (0-6' BLS)

NOTES

1. All concentrations are shown in $\mu g/L$.
2. The plume extent was generalized from and interpolated between sample locations. Information on actual conditions exists only at the specified locations.
3. All samples were collected in April/June 1999.
4. The Vinyl Chloride MCL equals 2 $\mu g/L$.

DATA SOURCES

1999 Compliance Plan Annual Sampling Event.

FIGURE 3.15
Distribution of Vinyl Chloride in the Surficial Aquifer at Site SS051
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

The extent of vinyl chloride is more limited in extent than its precursors PCE, TCE and total 1,2-DCE. As presented in **Figure 3.15**, vinyl chloride is found in a contiguous plume that begins at the source area in Zone 3 and migrates eastward ending in the southwest corner of East Kelly. Further downgradient, isolated occurrences of vinyl chloride exist and are very limited in extent.

The highest concentration of vinyl chloride is still found in MW SS037MW027. This well has shown increasing concentrations of vinyl chloride and 1,2-DCE since the beginning of the interim remedial pumping system. A possible cause of this could be influence from Site S-8. The increased pumping activity in the southernmost recovery well could be drawing these contaminants (known to be of concern at Site S-8) into the capture zone of Site MP. Also, benzene and chlorobenzene contamination from Site S-8 could be enhancing PCE and TCE degradation in the area near this well, causing 1,2-DCE and vinyl chloride concentrations to increase. Similar trends are seen in MWs SS040MW017 and SS037MW038.

3.2.4 Existing Source Control Measures

3.2.4.1 Site SS051

Interim source-control measures for the Site SS051 plume have focused on preventing the contaminated groundwater from migrating off site and include installing (March 1999) horizontal and vertical recovery systems along the entire eastern and southern boundaries of East Kelly. These wells effectively create a hydraulic barrier for further off-base migration of contaminated groundwater originating from Site SS051; this system also, at least, partially captures the Site MP plume.

The horizontal recovery system, started in July 2000, is currently pumping about 450 gallons per minute (gpm). The groundwater is treated by an ultraviolet oxidation (UVOX) process in a treatment plant located in the southeast corner of East Kelly. The UVOX process destroys the CVOCs, and the treated groundwater is discharged through the National Pollution Discharge Elimination System (NPDES) permitted outfall to Six Mile Creek. The approximate locations of the horizontal wells are shown on **Figure 3.16**.

3.2.4.2 Site MP

In 1995, a five-well pump and treat system was installed to prevent the off-site migration of the groundwater contamination from the Site MP source area. From 1997 to 1998, this five-well system was evaluated and optimized. A more effective two-well recovery system was designed and installed in March 1998. Since the optimized recovery system began operation, downgradient contaminant concentrations have decreased significantly.

A slurry wall (about 300 feet by 300 feet) was constructed in March through December 1999 to enclose the DNAPL source and contaminated soil beneath the footprints of the former buildings. The slurry wall extends from the ground surface to the top of the Navarro Clay.

Although there appears to be some degree of hydraulic communication between groundwater inside and outside the wall, a pumping well inside the wall is able to maintain an inward gradient. Over 2,000 gallons of DNAPL have been removed from the site and properly disposed of off-base since March 1999. **Figure 3.17** shows the location of the slurry wall and recovery wells.

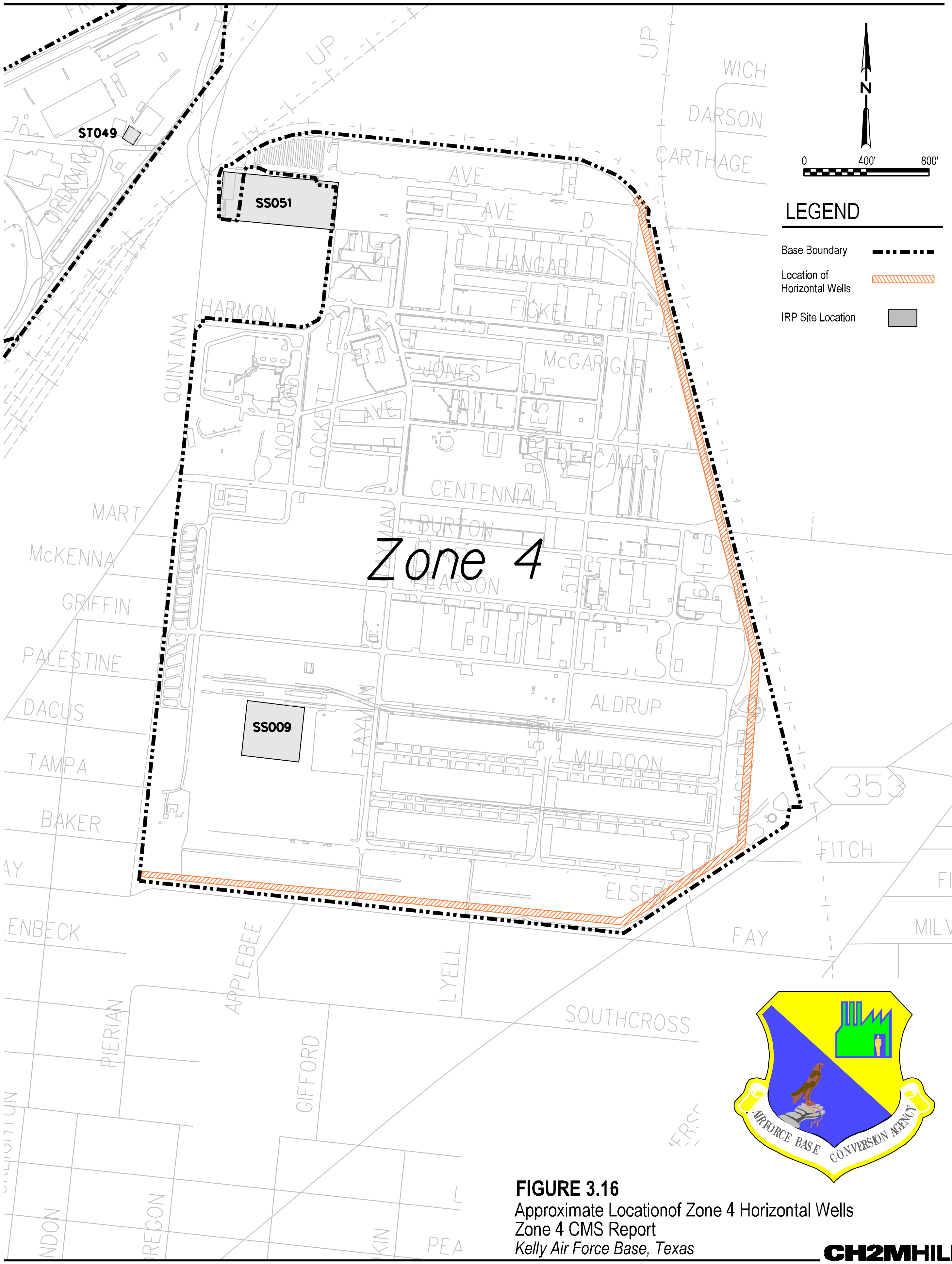


FIGURE 3.16
Approximate Locationof Zone 4 Horizontal Wells
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

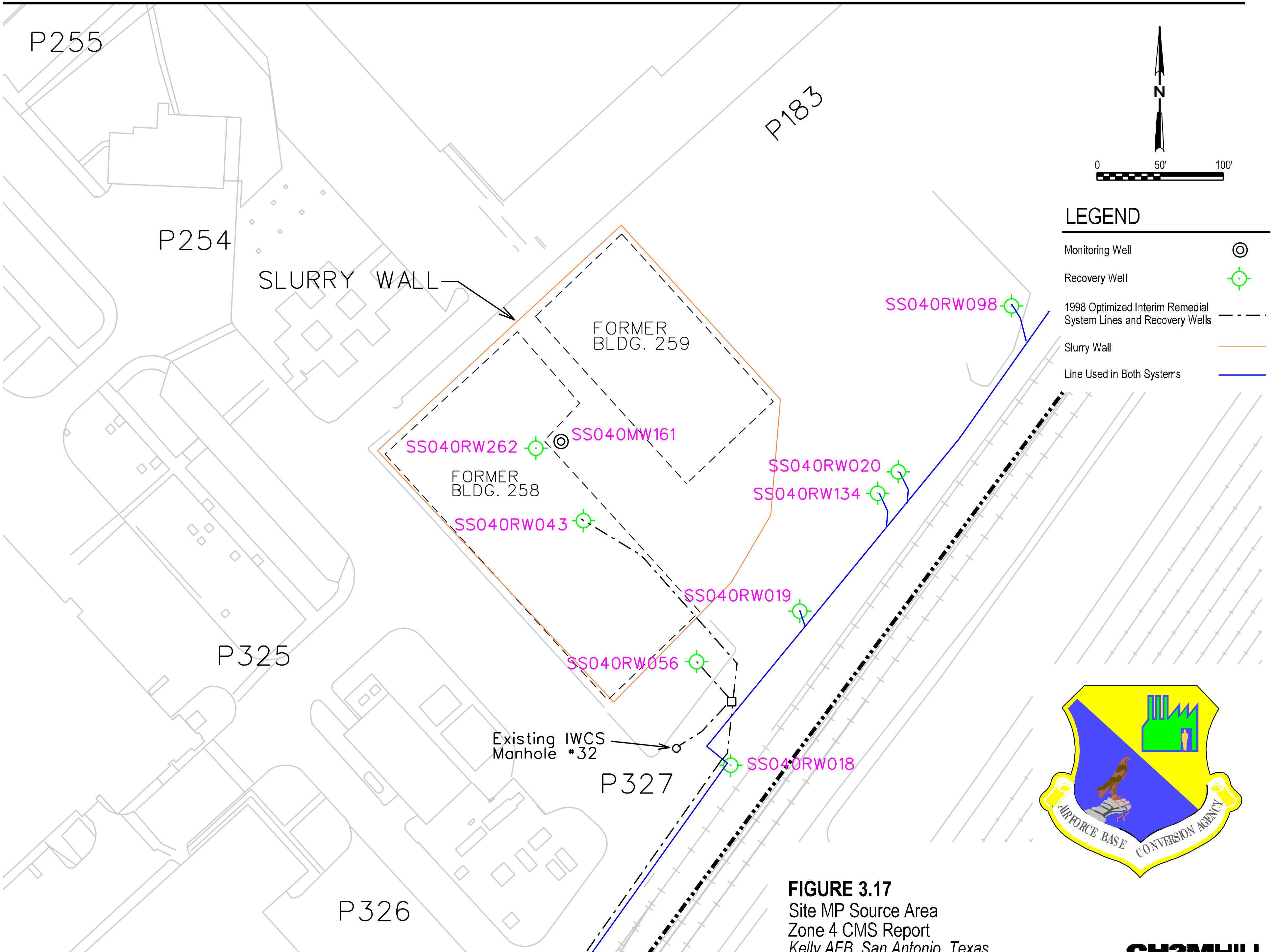


FIGURE 3.17
Site MP Source Area
Zone 4 CMS Report
Kelly AFB, San Antonio, Texas

CH2MHILL

3.2.5 Natural Attenuation

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem." Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

3.2.6 Summary of the Human-Health Risk Assessment

Potential human health risks were evaluated for Kelly AFB Zone 4 OU-2 shallow groundwater in the areas of East Kelly and extending off base toward the east and southeast. The four potentially exposed human populations at Zone 4 OU-2 include the following:

- Current and future on-base workers
- Current and future off-base residents using groundwater for irrigation purposes
- Future off-base residents using shallow groundwater for domestic purposes
- Youths using off-base surface water (impacted by groundwater) for recreational purposes such as wading

Since shallow groundwater on base is not used for any purpose, on-base worker exposure scenarios involving direct contact with groundwater were considered incomplete. Inhalation of indoor air by on-base workers, from VOC migration from groundwater into buildings, was considered a potentially complete pathway. However, a screening-level evaluation of the indoor air pathway indicated that there would not be significant exposure of on-base workers by this pathway. Therefore, quantitative estimates of risks associated with exposure of the on-base workers were not included in this (HHRA).

Potential exposure routes that were quantitatively evaluated for the off-base residential irrigation and off-base residential scenarios include direct contact and inhalation of VOCs while irrigating and showering, respectively. Inhalation of indoor air from migration of VOCs from groundwater into buildings was also considered potentially complete for off-base residents. However, as in the on-base worker scenario, the screening-level evaluation of the indoor air pathway for off-base residents indicated that there would not be significant exposure because of this pathway. Therefore, quantitative estimates of risks associated with exposure to indoor air by the off-base residents were not included in this HHRA. Potential routes of exposure to groundwater discharging to seeps that were quantitatively evaluated for the off-base recreational youth scenario include dermal contact and incidental ingestion only.

EPA, under the Superfund program, generally considers action to be warranted when risks exceed 1×10^{-4}. Action generally is not required for risks falling within 1×10^{-6} and 1×10^{-4}; however, this is judged on a case-by-case basis (EPA, 1991). Under the existing State of

Texas Risk Reduction Rule, a cancer risk of 1 x 10^{-6} shall be used to establish media cleanup levels for each individual contaminant. Regulatory agencies generally do not require action when risks are below 10^{-6}. For non carcinogenic COPCs, an HQ or HI greater than 1.0 indicates that there is some potential for adverse non-cancerous health effects associated with exposure to site COPCs and actions may be necessary to reduce risk.

Risk calculations were performed separately for the Site SS040 off-base plume and the Site SS051 off-base plume. Of the three exposure scenarios evaluated, the future residential scenario (domestic use of potable groundwater) for the Site SS040 off-base plume results in an ELCR exceeding the EPA target risk level of 1 x 10^{-4} and non-cancer risks exceeding the EPA target risk level of an HI greater than 1.0. The hypothetical residential scenario results in several constituents exceeding an individual ELCR of 1 x 10^{-6}. It should be noted that domestic potable use of shallow groundwater is highly unlikely as potable water is supplied by a public distribution system under current and anticipated future conditions in OU-2. Therefore, risk estimates associated with this scenario are considered very conservative.

The ELCR for the current and future off-base residential irrigation exposure scenario for the off-base Site SS040 plume is within the EPA risk criteria; vinyl chloride exceeds an individual risk of 1 x 10^{-6} for the RME scenario. The offbase recreational exposure scenario involving exposure to groundwater seeps results in an ELCR less than 1 x 10^{-6} for the RME and CTE scenarios. Details of the risk estimates for these scenarios are described below.

3.2.6.1 Site SS040 Off-base Plume Results

Under the current and future off base residential irrigation scenario, the potential HI is less than 1.0 for the RME and CTE scenarios. The potential cumulative ELCR from all carcinogenic COPCs is 6 x 10^{-6} for the RME scenario and 1 x 10^{-6} for the CTE scenario. The primary contributor to risk is vinyl chloride.

Under the hypothetical offbase residential scenario (domestic potable use of groundwater), the potential HIs for non-cancerous effects are 17 and 13 for the RME and CTE scenarios, respectively. The primary contributors to non-cancerous risk are cis-1,2-dichloroethylene, trichloroethene and vinyl chloride. The potential cumulative ELCR from all carcinogenic COPCs is 2 x 10^{-3} and 4 x 10^{-4} for the RME and CTE scenarios, respectively. The primary contributors to risk are vinyl chloride, tetrachloroethene and trichloroethene.

The EPC for vinyl chloride is 61 μg/L, which is considerably above the federal drinking water standard of 2 μg/L. The EPC for tetrachloroethene is 130 μg/L, which is considerably above the federal drinking water standard of 5 μg/L. The EPC for trichloroethene is 160 μg/L, which is considerably above the federal drinking water standard of 5 μg/L. The EPC for cis-1,2-dichloroethylene is 1200 μg/L, which is considerably above the federal drinking water standard of 70 μg/L.

The results of evaluating the Site SS040 off-base plume indicate that risk estimates for the off-base residential irrigation setting are within the limits of the regulatory risk criteria of 1 x 10^{-4} and 1 x 10^{-6}. The risk estimates under the hypothetical off base residential exposure setting (domestic use of potable groundwater) indicate that the regulatory risk thresholds are exceeded, and the Site SS040 off base groundwater plume will be evaluated as part of the Corrective Measures Study for Zone 4 OU-2.

3.2.6.2 Site SS051 Off-base Plume Results

Under the current and future off-base residential irrigation scenario, the potential HI is less than 1.0 for both the RME and CTE scenarios. The potential cumulative ELCR from all carcinogenic COPCs is less than 1×10^{-6} for both the RME and CTE scenarios.

Under the hypothetical off-base residential setting (domestic use of potable groundwater), the potential HI is less than 1.0 for both the RME and CTE scenarios. The potential cumulative ELCR from all carcinogenic COPCs is 2×10^{-5} and 4×10^{-6} for the RME and CTE scenarios, respectively. The primary contributors to risk are tetrachloroethene and trichloroethene.

The EPCs for tetrachloroethene (12 μg/L) and trichloroethene (37 μg/L) are above the federal drinking water standard of 5 μg/L.

The results of evaluating the Site SS051 off-base plume indicate that risk estimates for the off-base residential irrigation settings are less than 1×10^{-6}. EPA does not generally require any actions for risk falling below 1×10^{-6}. Under the off-base residential exposure setting (domestic use of potable groundwater), risk estimates are within the limits of the regulatory risk criteria of 1×10^{-4} and 1×10^{-6}.

3.2.6.3 Groundwater Seeps

Under the current and future off-base recreational youth scenario, the potential HI is less than 1.0 for both the RME and CTE scenarios. The potential cumulative ELCR from all carcinogenic COPCs is less than 1×10^{-6} for both the RME and CTE scenarios. The results of evaluating groundwater seeps indicate that risk estimates for the off-base recreational youth setting are less than 1×10^{-6}.

3.2.7 Summary of the Ecological Risk Assessment

An ERA was conducted for OUs 1 and 2 at Kelly AFB IRP Zone 4. This ERA was conducted using current TNRCC guidelines. This ERA was conducted to support closure activities for soil and groundwater according to the TNRCC Risk Reduction Rules (30 TAC Chapter 335, Subchapter S).

This ERA was conducted in accordance with the August 28, 2000 TNRCC publication "*Guidance for Conducting Ecological Risk Assessments at Remediation Sites in Texas,*" draft final. The TNRCC guidance describes a three tiered approach for conducting ERAs, of which Tiers 1 and 2 were completed in this report. The Tier 1 exclusion criteria checklist provides conditions, under which an affected property may be excluded from further ecological assessment, based on the absence of any complete or significant ecological exposure pathways. If the exclusion criteria are not met, the site requires further evaluation. The Tier 2 Screening Level Ecological Risk Assessment (SLERA) involves a comparison of COCs to background levels and screening ecological benchmarks to determine which COCs can be eliminated from further evaluation.

3.2.7.1 Ecological Setting

Kelly AFB Zone 4 is an active, primarily industrialized facility comprised of developed or disturbed land in an urban industrial setting. It is approximately 400 acres in size and is completely surrounded by a security fence. Approximately 65 percent of the zone consists of office buildings, large warehouses, paved and gravel parking lots, and paved roads. The remaining pockets of undeveloped land contain routinely maintained grass lots and occasionally a variety of landscape shrubs and trees.

Overall, the areas available as ecological habitat are small in area, isolated, heavily disturbed and unattractive to wildlife. There are no forested, brushland, wetland, or undisturbed old field areas within Zone 4 that would serve as valuable terrestrial habitat. Small mammal and bird use is expected to be minimal as a result of ongoing disturbance by light industrial activities and regular ground maintenance. There are no perennial or intermittent surface water bodies within Zone 4; thus, there is no onsite aquatic habitat. Nearby Six Mile Creek is an intermittent, almost entirely concrete lined drainage ditch outside the eastern boundary of the installation. The San Antonio River is located approximately three miles east of Kelly AFB. It is characterized as a perennial freshwater stream with use classifications identified as contact recreation and high quality aquatic life. There are no wetlands on Zone 4.

Wildlife species observed on-site are those generally adapted to living in disturbed open areas. Observed wildlife include black-tailed jackrabbit, eastern fox squirrel, Mexican ground squirrel, great-tailed grackle, mourning dove, white-winged dove, European starling, and northern mockingbird. There are no known occurrences of federal or state listed threatened or endangered plant or animal species, or natural communities, within all of Kelly AFB, including East Kelly.

3.2.7.2 Tier 1 Results

The purpose of the Tier I ERA checklist is to characterize the ecological setting of the affected property associated with each site and to determine the existence of complete or potentially significant ecological exposure pathways through the use of exclusion criteria. Exclusion criteria refer to those conditions of an affected property that preclude the need for a formal ERA because of incomplete or insignificant ecological exposure pathways. The checklist is designed as an early stage assessment of the affected property and requires only general information on site conditions such as which media contain COCs, general extent of the affected media, and attractiveness of the area to ecological receptors. The conclusions from the Tier I ERA checklists are as follows:

- Site SS051 meets the exclusion criterion for the terrestrial setting, thus this site does not require further evaluation in a Tier 2 ERA. However the exclusion criterion for surface water/sediment exposure was not met because of the demonstrated complete groundwater to surface water pathway. Since the groundwater plume is not considered part of OU-1, it is evaluated separately as OU-2.
- Site AOC MW160 meets the exclusion criterion for the terrestrial setting, thus this site does not require further evaluation in a Tier 2 ERA. However, the exclusion criterion for surface water/sediment exposure was not met because of its potential as a secondary source of contaminant release to groundwater. Since the groundwater plume is not considered part of OU-1, it is evaluated separately as OU-2.
- Site AOC MW125 meets the exclusion criterion for the terrestrial setting, thus this site does not require further evaluation in a Tier 2 ERA. However, the exclusion criterion for surface water/sediment exposure was not met because of a potential for leaching of soil

contaminants to groundwater at this predominantly unpaved site. Since the groundwater plume is not considered part of OU-1, it is evaluated separately as OU-2.

- The OU-2 groundwater plume does not meet the exclusion criteria since the plume has been demonstrated to contribute volatile organic contaminants into the San Antonio River zone of discharge. OU-2 should proceed to a Tier 2 ERA.

3.2.7.3 Tier 2 Results

The Zone 4 OU-2 groundwater plume was identified as not meeting the Tier 1 exclusion criteria, therefore this operable unit has been carried forward into a Tier 2 screening level assessment. The Tier 2 SLERA process includes 10 stepwise required elements which present four potential exit points from the ERA, or at least points for elimination of particular COCs or media.

The Tier 2 SLERA screening process involves the following steps:

- Identify COCs for each affected environmental medium.
- Compare maximum detected COC concentrations to background levels, and eliminate those COCs below background.
- Retain COCs that are considered bioaccumulative compounds.
- Compare maximum detected COC concentrations to TNRCC ecological benchmarks, eliminate COCs below these benchmarks, and retain all other COCs.

Groundwater is the only exposure medium evaluated for OU-2. A groundwater plume does extend from the general location of East Kelly AFB (Zone 4) to the San Antonio River where groundwater seeps do occur. Two sources of groundwater data were evaluated in this COC screening analysis; groundwater data from wells within the zone of discharge to the San Antonio River as collected by CH2M HILL (CH2M HILL, 2000), and groundwater seep/spring data sampled along the western shoreline of the San Antonio River as collected by the San Antonio River Authority (SARA)(SARA, 2000).

3.2.7.4 Zone of Groundwater Discharge COC Screening Analysis

The zone of groundwater discharge to the San Antonio River was determined to occur east of Loop 410, from the vicinity of Theo Street south to Mission Road.

The first screening step involved comparison of the maximum detected zone of discharge data against background groundwater concentrations. Six inorganic COCs below background were eliminated from further evaluation. The second screening step involved an evaluation to identify COCs considered to be bioaccumulative chemicals. None of the remaining inorganic and organic COCs were identified as bioaccumulative compounds.

In the final screening step, the maximum detected concentrations of remaining COCs were compared to ecological screening benchmarks. The results of the benchmark screening indicated that five inorganics and 13 organics had maximum concentrations below screening benchmarks, and were thus eliminated from further evaluation. The remaining COCs included manganese, and bis (2-ethylhexyl) phthalate. Based on the information below will not be considered further for the following reasons:

- Manganese was detected in all four groundwater samples, ranging from 8 μg/L to 1000 μg/L. The maximum concentration was the only detection that exceeded the groundwater background concentration of 342 μg/L. However, the average concentration of manganese in the discharge zone is 294 μg/L, which is less than the background value. Manganese is also expected to oxidize at the point of discharge and precipitate out of solution. Therefore, manganese will not be considered further as an ecological COC.

- Bis (2-ethylhexyl) phthalate was detected in just one of the four groundwater zone of discharge samples. The single detected concentration of 8 μg/L slightly exceeded the screening benchmark of 7 μg/L. This is generally considered common laboratory contaminant. In accordance with the *EPA Contract Laboratory Program (CLP) National Functional Guidelines (NFG) for Organic Data Review* (February 1994), common laboratory contaminants should be considered a positive result in environmental samples, only if the concentration detected in the sample exceeds 10 times the concentration detected in any blank.

  Bis(2-ethylhexyl)phthalate was detected at 13 locations in the entire OU-2 groundwater plume with concentrations ranging between 1 μg/L and 15 μg/L. Bis(2-ethylhexyl) phthalate was also detected in an ambient condition blank and a laboratory blank at concentrations of 61 μg/L and 4 μg/L, respectively. Therefore, the concentration of bis(2-ethylhexyl)phthalate detected in groundwater samples is considerably less than 10 times the concentration detected in any blank. Consequently, bis(2-ethylhexyl)phthate is not considered a positive result and will not be carried forward as a COC.

As a result, none of the chemicals detected in the groundwater zone of discharge to the San Antonio River require further evaluation in the screening ecological risk assessment.

3.2.7.5 Groundwater Seep COC Screening Analysis

In the fall and winter of 1999, SARA conducted a water quality (and biological) survey to assess potential impacts from the organic contaminants in the groundwater plume associated with Kelly AFB. Samples of groundwater seeps and springs were collected from 12 locations along the banks of the San Antonio River and its tributaries within the zone of discharge. Target volatile organic analytes were limited to 1,1-DCE, trans-1,2-DCE, cis-1,2-DCE, PCE, TCE, and vinyl chloride.

Three organic COCs were detected in the groundwater seeps and springs. None of the organic COCs are considered bioaccumulative compounds. The maximum detected concentrations of the COCs were compared to ecological benchmarks. The COC screening analysis of groundwater seep data resulted in the elimination of all COCs from further evaluation.

The evaluation of volatile contaminants in groundwater seeps flowing into the San Antonio River indicated that none of the detected contaminants exceeded screening toxicity values.

In addition to the lack of COCs identified in the zone of discharge and groundwater seeps, a biological survey of the San Antonio River segment that receives groundwater discharge from OU-2 indicated that fish and invertebrate communities were not being affected by water quality. A combined water quality/biological survey was conducted by the SARA along the San Antonio River to document conditions of the aquatic ecosystems (SARA, 2000). The following key results were obtained from the investigation:

- Aquatic fish and invertebrate diversity along the upper San Antonio River may be limited by habitat conditions identified as partially supporting.
- The diversity of benthic macroinvertebrates was rated as “good to very good” within the study area indicating water quality conditions were capable of sustaining sensitive species.
- None of the San Antonio River surface water samples had detectable concentrations of the targeted VOCs. As such, it was concluded that the detected VOCs in emerging groundwater quickly volatize when exposed to the atmosphere and were having no impact to the San Antonio River and its tributaries.

3.2.7.6 Future Groundwater Concentrations

Preliminary groundwater modeling results have indicated that the OU-2 plume that is discharging to the San Antonio River has peaked in concentration and will not increase in the future. Also, groundwater concentration trends presented in the RFI report (CH2M HILL, 2000) show that the concentrations in the plume are stable or decreasing, particularly at the SS051 source area. The zone of discharge of the plume is primarily sourced by SS051 and therefore cannot increase in the future. Risk characterization using current conditions (current conditions are prior to any remedial action) represent the highest potential risk since future conditions can be no worse that current conditions based on modeling results and water quality trends.

SECTION 4.0

Corrective Action Objectives

This section presents the preliminary Corrective Action Objectives (CAOs) for Zone 4 OU-2 groundwater targeted for corrective action. The findings of the Zone 4 RFI, January 2001 and public comment and input provided as part of the overall Zone 4 CMS work approach were all considered when developing these objectives.

The overall goal for this project is to achieve drinking water standards in the shallow groundwater as defined by the maximum contaminant levels (MCLs). Due to the size and complexity of the overall Zone 4 shallow groundwater plume, CAOs may vary based on the location and type of remedy being considered. Remedial technologies are being evaluated for application in the following four primary areas of the plume: source areas, areas with high concentrations, plume centerlines or primary flowpaths, and areas of low concentrations. CAOs can vary from containing a source area, to reducing concentrations along plume centerlines, to achieving MCLs in other areas of the plume. The combined effect of the CAOs results in the overall reduction in concentrations of the plume to below MCLs.

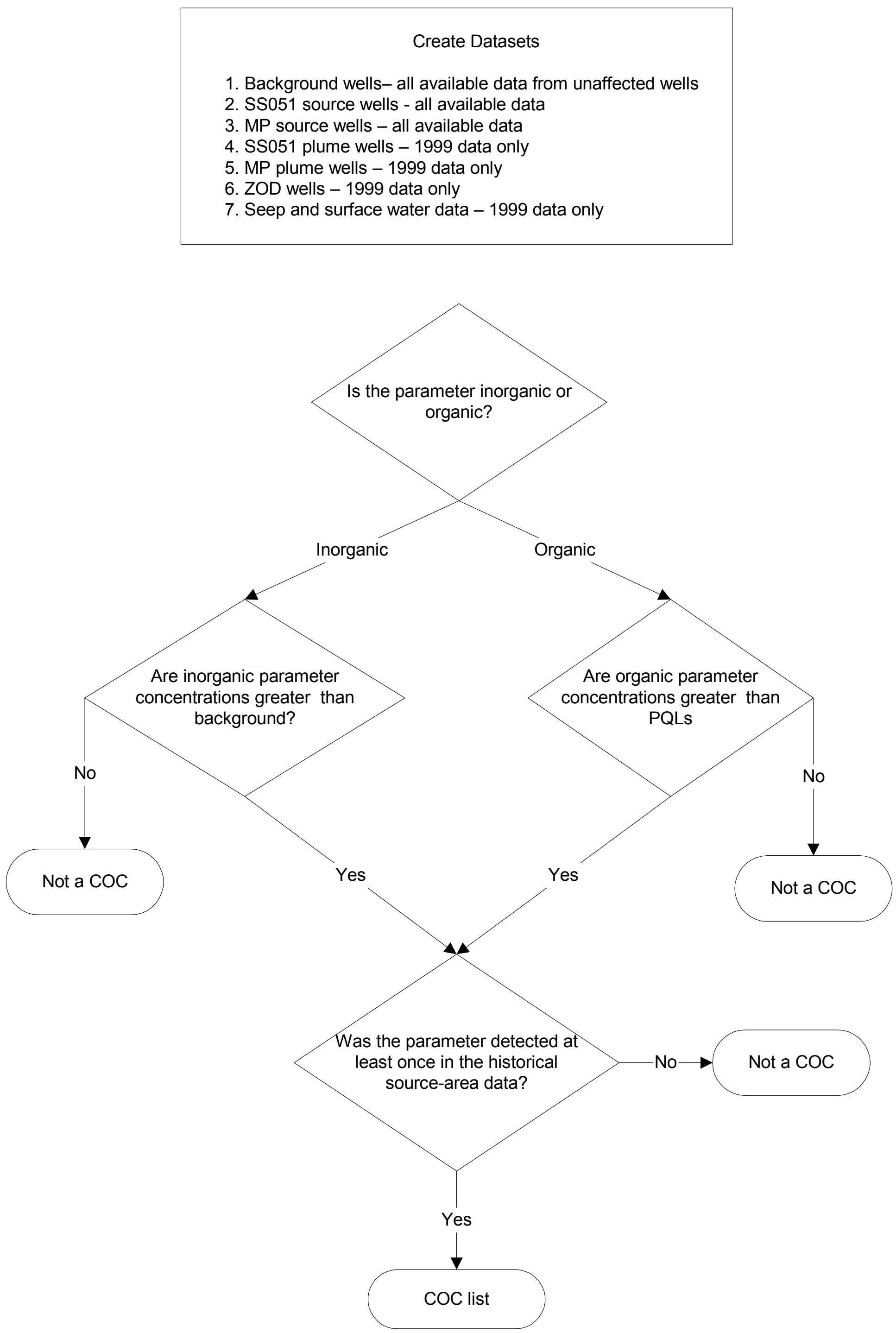
4.1 Contaminant of Concern Selection Process

Figure 4.1 shows the process used to select contaminants of concern (COCs) during the Zone 4 RFI. Parameters that were detected at concentrations greater than background (inorganic parameters) and PQLs (organic parameters) and were detected in at least one sample from the historical source-area data summaries were considered COCs. The COCs were then compared to the TNRCC MSCs. **Table 4.1** lists plume parameters exceeding the MSCs.

TABLE 4.1
Plume Parameters Exceeding Medium-Specific Concentrations
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

SS051 Plume	MP Plume
Total chromium	Arsenic
PCE	Benzene
DCE	Total chromium
TCE	PCE
Vinyl chloride	Total 1,2-DCE
	TCE
	Vinyl chloride

FIGURE 4.1
COC Selection Process
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas



4.2 Preliminary Corrective Action Objectives

The overall goal for the project is to achieve the United States Safe Drinking Water Act (SDWA) MCLs in the shallow groundwater. Considering this goal, the COA is to meet the MCLs in a reasonable time frame for the contaminants in the Site MP and Site SS051 plumes (listed in **Table** 4.**2)**.

TABLE 4.2
TNRCC MSCs for Groundwater
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Contaminant	MCL (µg/L)
Trichloroethene	5
Tetrachloroethene	5
Cis-1,2-Dichloroethene	70
Vinyl Chloride	2
Arsenic[1]	50
Benzene[1]	5
Total Chromium[1]	100

µg/L micrograms per liter

Note:
[1] Arsenic, Benzene and Total Chromium are only COCs at the source areas and not in the off-base plume

SECTION 5.0

Identifying and Screening Technologies

This section presents the initial steps of the multi-step process for developing corrective measures alternatives. This multi-step process is part of the EPAs recommended approach for conducting RCRA Corrective Actions (*RCRA Corrective Action Plan, OSWER Directive 9902.3-2A* (EPA, 1994). The following steps of the process are covered in this section:

(1) Identify corrective measure technologies: This step involves identifying potential technology types that are applicable to each general response action.

(2) Screen remedial technologies: This step screens out technologies if they cannot be technically implemented at the site. The evaluation is based on effectiveness and implementability.

(3) The technologies that pass the initial screening presented herein are retained for development of CMAs and presented in Section 6.0 of this report.

5.1 Identifying and Screening Technologies

The screening of technologies takes a comprehensive list of potentially applicable technologies and eliminates those that are either technically ineffective or not implementable based on site conditions, contaminants present, contaminant characteristics or availability of technologies. **Table 5.1** summarizes the identification and screening of technologies for shallow groundwater. **Table 5.2** details all technologies that were screened to identify potentially applicable technologies for sites MP and SS051 and the off-base plume.

TABLE 5.1
Identification and Screening of Technologies
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

	Effectiveness	Implementation	Relative Cost
Ex situ: Hydraulic Containment			
Vertical wells (pump and treat)	Low to Medium	Very Difficult	High
Horizontal wells and drain lines (pump and treat)	Low to Medium	Difficult	High
In situ Physical-Chemical Treatment			
Reactive barriers	Medium	Difficult	Moderate
Air injection and vapor removal	Medium	Very difficult	High
Dual-phase vapor extraction and groundwater extraction	Low	Very difficult	High

TABLE 5.1
Identification and Screening of Technologies
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

	Effectiveness	Implementation	Relative Cost
In situ oxygen treatment	Medium	Very difficult	High
In situ chemical reduction	Low	Very difficult	High
In situ Thermal Treatment			
Steam enhanced extraction	Low	Very difficult	High
Dynamic underground stripping	Low	Very difficult	High
In situ Biological Treatment			
Bioremediation and bioventing	Low	Very difficult	Moderate
Aerobic cometabolic bioremediation	Medium	Implementable	Moderate to high
Anaerobic bioremediation	Low	Very difficult	Moderate
Phytoremediation	Medium	Implementable	Low
Monitored natural attenuation	Low	Implementable	Low

The effectiveness and implementability of each technology were evaluated to determine if it could potentially be combined into a corrective measures alternative that could satisfy the CAOs. Technologies deemed to have a low effectiveness or difficulty implementation were not retained for further evaluation.

Under the effectiveness evaluation, technologies can be evaluated to have a high, medium, or low probability of effectiveness as follows:

- **High probability of effectiveness:** Technologies assessed to have a high probability of effectiveness are very likely to be able to meet the CAOs.
- **Medium probability of effectiveness:** Technologies described as having a medium probability of effectiveness may not be completely successful alone or in combination with other technologies in meeting the CAOs. This could be a consequence of specific site conditions (e.g., depth to contaminated groundwater or heterogeneity) that may inhibit the effectiveness of a process option.
- **Low probability of effectiveness**: Technologies evaluated to have a low probability of effectiveness are not likely to meet the CAOs because they are not applicable to site conditions, media, contaminants present, contaminant concentrations or site characteristics.

Under the implementability evaluation, technologies could be evaluated to be implementable, difficult to implement, or very difficult to implement. Each of these are defined as follows:

- **Implementable**: Technologies have been proposed to be implementable if the equipment, supplies and technical expertise are commercially available. An

TABLE 5.2 (CONTINUED)
Identification and Screening of Technologies for Zone 4 Shallow Groundwater
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

General Response Actions	Corrective Measures Technology	Technology Components	Description	Effectiveness	Implementability	Relative Cost	Recommendation	Screening Comments
		Monitoring	Continue sampling and analysis of groundwater.	None, other than documenting water quality variations (if any) over time.	Implementable.	Low		Typically applied in conjunction with other technologies as a means of evaluating performance of a corrective measure.
Containment	Vertical physical barriers	Grout curtains	Create physical barrier to groundwater flow by injecting grout into the subsurface. To effectively contain dissolved constituents like those in the Zone 4 OU-2 shallow groundwater, the barriers must be anchored or "keyed" into a relatively low-permeability unit such as the Navarro Clay. Also, to prevent groundwater migration around barriers and potential surface flooding, this technology would likely include fluid control measures.	Low probability of being effective. Effectiveness limited by the expected complications of forming a continuous "curtain" via injection into complex geologic units comprising the shallow alluvium.	Implementable in areas of relatively small size and/or in nonresidential areas. Very difficult to implement in off-site areas given the size of the affected off-site areas and the complex geology of the shallow alluvium. Typically involves large amount of heavy construction, noise, and traffic disruption.	High	Not retained	Not retained due to low probability of being effective.
		Slurry walls	Create physical barrier to groundwater flow by installing soil-based slurry wall. To effectively contain dissolved constituents like those in the Zone 4 OU-2 shallow groundwater, barriers must be anchored or "keyed" into a relatively low-permeability unit such as the Navarro Clay. Also, to prevent groundwater migration around barriers and potential surface flooding, this technology would likely include fluid control measures.	Medium probability of being effective at isolating active sources like the PCE DNAPL pool at Site MP. Low probability of being effective for off-site plumes.	Implemented at Site MP. Implementable in areas of relatively small size and/or in nonresidential areas. Difficult to implement in off-site areas given the size of the affected off-site areas. Typically involves large amount of heavy construction, noise, and traffic disruption.	Moderate	Not retained	Although considered effective for isolating the PCE DNAPL pool at Site MP, this technology is not considered effective for Site SS051 since RFI results do not indicate the presence of an active source of TCE contamination.
		Sheet pile walls	Create physical barrier to groundwater flow by installing interlocking, steel-sheet piles. To effectively contain dissolved constituents like those in the Zone 4 OU-2 shallow groundwater, barriers must be anchored or "keyed" into a relatively low-permeability unit such as the Navarro Clay. To prevent groundwater migration around barriers and potential surface flooding, this technology would likely include fluid control measures.	Low probability of being effective. Joints between sheet piles are vulnerable to leakage making this technology typically much less effective than slurry wall technology.	Moderately difficult to implement. This technology typically involves large amount of heavy construction, noise, vibrations, and traffic disruptions.	High	Not retained	
		Soil mixing	Create a physical barrier to groundwater flow by mixing an additive into the soil to produce a hard mass that acts as a barrier. To effectively contain dissolved constituents like those in the Zone 4 OU-2 shallow groundwater, barriers must be anchored or "keyed" into a relatively low-permeability unit such as the Navarro Clay. To prevent groundwater migration around barriers and potential surface flooding, this technology would likely include fluid control measures.	Low probability of being effective. To be effective, complete mixing of soil and additives to the top of the Navarro Clay must be accomplished.	Very difficult to implement. Involves very close-spaced drill holes, heavy construction equipment, noise, construction waste, and traffic disruption.	High	Not retained	

TABLE 5.2 (CONTINUED)
Identification and Screening of Technologies for Zone 4 Shallow Groundwater
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

General Response Actions	Corrective Measures Technology	Technology Components	Description	Effectiveness	Implementability	Relative Cost	Recommendation	Screening Comments
Hydraulic Contaminant Removal	Pump and treat	Vertical wells	Extract contaminated groundwater by pumping vertical wells. The vertical wells would be strategically located and pumped at designated rates so that contaminated groundwater would be removed. Since contaminated groundwater is removed, groundwater treatment would be included with this technology.	Low to medium probability of being effective at source areas. Low probability of being effective for off-site plumes since wells would need to be closely spaced and potentially placed at particular residences and/or businesses to be effective.	Implemented at Site MP. Implementable in areas of relatively small size and/or in nonresidential areas. Difficult to implement in off-site areas considering the complex geology of the shallow groundwater system and the size of the area of affected groundwater off site. Some heavy construction equipment, noise, and traffic disruption expected.	High	Retained	Significant costs expected associated with detailed geologic investigations focused on optimizing well placement. It may be expected these investigations would involve noise, traffic disruptions, and property access issues. System installation (treatment plants construction, pipeline installation) system operation, and maintenance will involve significant noise, traffic disruptions, and property access issues.
		Horizontal wells, trenches, and drain Lines	Extract contaminated groundwater by pumping horizontal wells, trenches, and/or drain lines. These systems would be strategically located and pumped at designated rates so that contaminated groundwater would be removed. Since contaminated groundwater is removed, groundwater treatment would be included with this technology.	Low to medium probability of being effective. Considered more effective than vertical wells for off-site plumes since performance of horizontal systems are less sensitive to geologic complexities.	Difficult to implement. Implemented along the eastern and southern boundaries of East Kelly. Experience with the installation of this technology at East Kelly indicates that subsurface variations in the Navarro Clay are expected to increase difficulty of installation. Some heavy construction equipment, noise, and traffic disruption expected. Dust and construction waste generation expected to be minimal.	Medium	Retained	Although some geologic investigation may be expected, it would likely be less than that required for vertical wells. Would include groundwater treatment prior to discharge or reinjection.
In situ chemical and physical treatment	Chemical treatment	Chemical reduction: ZVI walls	Place a permeable reaction wall across the flow path of a contaminant plume. Contaminants are chemically degraded as the water flows through the wall.	Medium probability of being effective. If the walls are placed within the plume, they are expected to speed the natural flushing of the contaminants downgradient of the wall.	Moderately difficult to Implement. Construction-related disturbances (dust, noise, and traffic disturbances) may increase the difficulty of implementing this technology particularly in dense residential areas. Utilities expected to increase the difficulty of installing the walls.	Medium	Retained	Barriers may be installed along roads to reduce construction impacts, although utility and traffic impacts are expected to still be high.
		Chemical reduction: ZVI slurry	Inject a permeable reactive slurry using a system of vertical wells placed across the flow path of a contaminant plume.	Medium probability of being effective for source area Site SS051 and for Site MP (outside the slurry wall system). Low probability of being effective for off-site plumes since wells would need to be closely spaced (less than 25 feet) and potentially placed at particular residences and/or businesses to be effective. This technology is most effective in uniform, coarse-grained aquifers.	Implementable in areas of relatively small size and/or in nonresidential areas. Very difficult to implement in off-site areas given the size of the affected off-site areas. Chemical injection wells would have to be spaced very close (less than 25 feet) to be effective. This will be very difficult to implement given the houses and other structures over the plumes.	High in off-site areas Medium at source areas	Retained for Site SS051 and Site MP source areas. Not retained for off-site plumes.	The very close spacing (less than 25 feet) of injection wells is expected to make this technology very difficult to implement in off-site areas.

TABLE 5.2 (CONTINUED)
Identification and Screening of Technologies for Zone 4 Shallow Groundwater
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

General Response Actions	Corrective Measures Technology	Technology Components	Description	Effectiveness	Implementability	Relative Cost	Recommendation	Screening Comments
		In situ oxygen treatment	Inject oxidizing liquid agents (peroxide, potassium permanganate, or ozone) to promote abiotic *in situ* oxidation of chlorinated organic compounds like those found in Zone 4 shallow groundwater. Injection could be carried out using horizontal wells.	Medium probability of being effective for source area Site SS051 and for Site MP (outside the slurry wall system). Medium probability of being effective for off-site plumes since wells would need to be closely spaced (less than 100 feet) and potentially placed at particular residences and/or businesses to be effective. This technology is most effective in uniform, coarse-grained aquifers.	Implementable in areas of relatively small size and/or in nonresidential areas. Very difficult to implement in off-site areas given the size of the affected off-site areas. Chemical injection wells would have to be spaced very close (about 100 ft) to be effective. Chemical storage and injection systems would have to be located within the neighborhoods.. Noise and traffic disruptions expected to be significant.	High in off-site areas Medium at source areas	Retained	Chemicals used for this technology may be hazardous to the public. Potassium permanganate is considered least hazardous, however, it has a bright purple color.
	Physical treatment	Air sparging/SVE (air injection/ vapor removal)	Construct a system of vertical and/or horizontal wells to allow both air injection (sparging) and vapor removal. The objective is to inject air into the contaminated groundwater removing contaminants by volatilization. Once volatilized, the vapor-phase contamination is removed, collected, and treated.	Medium probability of being effective for source area Site SS051 and for Site MP (outside the slurry wall system). Medium probability of being effective for off-site plumes since wells would need to be closely spaced (less than 60 feet) and potentially placed at particular residences and/or businesses to be effective. Potential exists for vapors to migrate past collection systems and harm the public or the environment.	Implementable in areas of relatively small size and/or in nonresidential areas. Very difficult to implement in off-site areas given the size of the affected off-site areas. Air injection wells would have to be spaced very close (less than 60 feet) to be effective. This will be difficult to implement given the houses and other structures over the plumes. Typically involves large amount of heavy construction, noise, and traffic disruption.	High in off-site areas Medium at source areas	Retained	To be effective a large number of wells would be required. Difficult to ensure capture of potentially hazardous vapors may pose unacceptable risk to the public.
		Dual-phase VE/GE	Apply a high-power vacuum system to simultaneously remove soil vapors, groundwater, and other liquid from the subsurface environments. The groundwater table is lowered, allowing vapor extraction to occur.	Low probability of being effective. This technology is most effective in medium to fine-grained aquifers. The groundwater flow rates at Zone 4 OU-2 may be too high to allow the water tabled to be lowered.	Very difficult to implement. Extensive subsurface delineation of each heterogeneous section expected for optimum well placement. This technology is better suited to high-concentration source areas.	High	Not retained	
		Phytoremediation: Poplar trees	Use trees to destroy contaminants, as well as remove groundwater. A row of trees can be planted where the groundwater is shallow to extract groundwater and contaminants.	Medium probability of being effective. Phytoremediation is most effective when contaminants are in shallow groundwater, within the root zone of plants. This only occurs along the ZOD of the SS051 plume near the San Antonio River. The effectiveness decreases substantially when the trees are dormant. Effectiveness only begins once the tree root system has been established.	Implementable. Continued maintenance is required to keep the trees alive and thriving.	Low	Retained	This technology is considered most applicable to areas along the San Antonio River where depths to shallow groundwater decrease.

TABLE 5.2 (CONTINUED)
Identification and Screening of Technologies for Zone 4 Shallow Groundwater
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

General Response Actions	Corrective Measures Technology	Technology Components	Description	Effectiveness	Implementability	Relative Cost	Recommendation	Screening Comments
In situ thermal treatment	Steam heating	Steam-enhanced extraction	Force steam into a groundwater system through injection wells to vaporize volatile and semivolatile contaminants. Vapors rise to the unsaturated zone, where they are removed by vacuum extraction and treated.	Low probability of being effective.	Very difficult to implement. This technology is better suited to high-concentration source areas. It has is not been proven on a large scale and would be very difficult to implement, especially under and around structures.	High	Not retained	Potential for risk to public safety using steam. Difficult to ensure capture of potentially hazardous vapors may pose unacceptable risk to the public
	Electrical heating	Six-phase electrical heating	Place electrodes in the ground so that electrical currents run between the electrodes. Heat is generated and contaminants are volatized. Contaminated vapors are collected in the vadose zone and treated above ground.	Low probability of being effective.	Very difficult to implement. This technology is better suited to high-concentration source areas. It has is not been proven on a large scale and would be very difficult to implement, especially under and around structures.	High	Not retained	Potential for risk to public safety using electrical heating. Difficult to ensure capture of potentially hazardous vapors may pose unacceptable risk to the public.
In situ biological treatment	Aerobic biodegradation	Bioremediation: bioventing	Deliver oxygen to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation. In conjunction with other systems, semivolatile compounds are potentially treatable *in situ*.	Low probability of being effective. The contamination exists below the water table so it would not be impacted by air injection in the unsaturated zone. Chlorinated solvents are not biodegradable under standard aerobic conditions.	Very difficult to implement.	Moderate	Not retained	
	Aerobic biodegradation	Aerobic cometabolic bioremediation	Use water-containing inducers (such as methane or toluene) and electron acceptor (oxygen) to enhance aerobic biodegradation. Inducers serve as carbon sources that activate aerobic enzyme systems known to degrade chlorinated VOCs (fortuitous cometabolism).	Medium probability of being effective. Still a developing technology. Its performance has been found to be variable.	Implementable. A large number of injection wells (vertical or horizontal) would be needed to inject the required chemicals. It is very difficult to achieve effective distribution of the chemicals. Continuous injection for a number of years may be required.	Moderate to high	Not retained	Handling of chemicals (methane) may be dangerous to public safety.
MNA	Anaerobic bioremediation	Anaerobic cometabolic bioremediation (enhanced microorganism breakdown)	Inject complex organic compounds into the groundwater to stimulate anaerobic microorganisms. These organisms use the injected compounds as their food source and respire (breath) chlorinated solvents.	Low probability of being effective. This technology has not been proven on a large scale, but is being applied at smaller sites. Potentially hazardous breakdown compounds may be produced by this process (i.e., vinyl chloride).	Very difficult to implement. Chemical injection points would have to be spaced very close (less than 25 feet) to be effective. This will be very difficult to implement given the houses and other structures over the plumes.	Moderate.	Retained	

TABLE 5.2 (CONTINUED)
Identification and Screening of Technologies for Zone 4 Shallow Groundwater
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

General Response Actions	Corrective Measures Technology	Technology Components	Description	Effectiveness	Implementability	Relative Cost	Recommendation	Screening Comments
	Natural reduction	Biodegradation, dispersion, dilution, volatilization, and sorption	Continually monitor the natural processes that result in the destruction and reduced mobility of contaminants. The processes include the following: a) Dilution resulting from dispersion and/or groundwater mixing b) Contaminant adsorption to the aquifer matrix c) Biodegradation (aerobic and anaerobic) d) Abiotic contaminant oxidation e) Hydrolysis	Low probability of being effective as a stand alone technology. Must be used in conjunction with other technologies. Once the on-base source is cut off, natural attenuation should result in the decrease in off-site groundwater concentrations. The length of time to reach MCLs is uncertain.	Implementable.	Low	Retained	Monitoring in order to confirm natural attenuation is occurring is required.

AFB	Air Force Base	PCE	tetrachloroethene
DCE	dichloroethene	RFI	RCRA Facility Investigation
DNAPL	dense nonaqueous phase liquid	SVE	soil vapor extraction
GE	groundwater extraction	VE	vapor extraction
MCL	maximum contaminant level	VOC	volatile organic compounds
MNA	monitored natural attenuation	ZVI	zero valent iron
OU	operable unit	ZOD	zone of discharge

implementable technology also has been proven full-scale or appears promising based on bench- or pilot-scale studies. Other factors that affect implementability are the time to design, construct, operate and site access and scale.

- **Difficult to implement:** Technologies identified as having a difficult implementation are those that have not been proven at full-scale, but have been proven on a pilot scale. Also, equipment or technical expertise may not be commercially available, construction impacts are expected to be significant, or operating conditions are difficult to maintain.
- **Very difficult to implement:** Technologies identified as very difficult to implement are those that may not be commercially available, have not been proven at the full- or bench-scale level, construction impacts are expected to be significant, or operating conditions are impossible to maintain.

5.2 Retained Technologies

The following technologies were selected as the most feasible for further evaluation based upon effectiveness and/or implementability:

- **Hydraulic Containment (Pump and Treat)**: Vertical and/or horizontal wells/drain lines for source areas and off-site plumes.
- ***In situ* Chemical Reduction:** Zero valent iron slurry for source areas and flow-through reactive walls for source areas and off-site plumes.
- ***In situ* Oxygen Treatment:** both source areas and off-site plumes.
- **Air Sparging/Soil Vapor Extraction (AS/SVE):** Both source areas and off-site plumes.
- **Phytoremediation:** Site SS051 plume zone of discharge (ZOD) near San Antonio River.
- **Anaerobic Cometabolic Bioremediation** (enhanced microorganism breakdown): Both source areas and offsite plumes.
- **Monitored Natural Attenuation (MNA):** Both source areas and offsite plumes.

These retained technologies have been used in developing corrective measures alternatives developed in Section 6.0. The general characteristics of the retained technologies are described below.

5.2.1 Pump and Treat

Pump and treat (hydraulic containment) strategy extracts groundwater through one or more types of wells and treats the contaminated groundwater in an aboveground treatment plant. After enough of the groundwater is pumped out of the ground, the contaminants begin to be flushed from the aquifer.

Groundwater can be pumped from vertical wells, from horizontally drilled wells, or from drain lines. The well spacing depends on geological and hydrogeological conditions in the aquifer, the availability of land and the speed with which the CAOs can be met.

The water pumped from the ground is treated through a water treatment system, such as air strippers, carbon filters or a UV/OX system. The treated water can then be discharged to a sanitary or storm sewer or surface body water. It may also be reinjected into the ground. Reinjection may speed the flushing of the contaminants from the ground, but it may be difficult to operate due to plugging of the reinjection wells. Reinjection also requires twice the level of effort without the double benefit.

5.2.2 *In situ* Chemical Reduction

5.2.2.1 Flow-Through Reactive Walls (Permeable Reactive Barriers)

In situ, or in place, flow-through reactive walls, or treatment walls, are structures installed underground to treat contaminated groundwater.

Treatment walls are put in place by first constructing a trench across the flow path of contaminated groundwater. The trench is then filled with a chosen material based on the types of contaminants found at a site. As the contaminated groundwater flows through the treatment wall, the contaminants are chemically changed into less toxic or nontoxic substances.

For chlorinated solvents, zero valent iron (ZVI) is the most commonly used treatment material. The ZVI (typically iron filings) will chemically reduce and strip off the chlorines from the solvents, converting them to harmless ethene.

Reactive barriers can effectively treat the water that passes through them, but they cannot treat pollutants that are already downstream. By cutting off the upgradient source, the downgradient-dissolved pollutants will eventually be remediated through natural attenuation.

5.2.2.2 Reactive Slurry

This technology delivers ZVI into groundwater systems by injecting reactive slurry containing colloidal-sized ZVI, water and nitrogen gas. The reactive slurry is injected into the aquifer via wells and treatment takes place below the ground surface. The nitrogen gas pressurizes the slurry for injection and maintains subsurface anaerobic conditions to ensure that the ZVI is not oxidized before it is delivered to the target treatment zone. As the contaminated groundwater flows through the treatment zone, the chlorinated solvents are chemically changed into less toxic or nontoxic substances.

To be effective, reactive slurry injection requires wells typically placed every 25 feet or less to clean up an area.

5.2.3 *In situ* Oxygen Treatment

In situ, or in place, oxygen treatment is a technology that uses chemicals to treat contaminated soils and groundwater. The chemicals are injected into the aquifer via wells and treatment takes place below the ground surface.

Two common compounds used for *in situ* oxidation are hydrogen peroxide and potassium permanganate; both can be used to treat the solvents present in shallow groundwater. Once the pollutants are exposed to the oxidizing chemicals, they are turned into carbon dioxide or less toxic or nontoxic substances through chemical reactions.

To be effective, *in situ* oxidation requires that relatively large amounts of oxidizing chemicals be injected into the ground. Injection wells typically must be placed every 100 feet or less to clean up an area. Typically, the chemicals must be reinjected twice for the process to be effective. Disadvantages of oxidation may include heat and gas generation, and the treatment may be detrimental to the native bacterial population.

5.2.4 Air Sparging/Soil Vapor Extraction (Air Injection/Vapor Removal)

Air Sparging (AS) may be designed with or without SVE, also called vapor removal. AS without SVE is designed to create a zone of increased oxygenation in the aquifer. The oxygenated zone enhances or stimulates the *in situ* biodegradation of contaminants that degrade under aerobic conditions. Systems without SVE must be tuned to provide enough oxygen to stimulate biodegradation without transferring the VOCs from the groundwater to the soil gas.

Air injection with SVE is a simple process that physically separates contaminants from groundwater by turning them into vapors or gases and then collecting them. Air sparging means pumping air into the ground below the water table. The air rises through the groundwater and pulls the pollutants out of the water. The vapors and gases are collected by applying a vacuum through a system of underground wells above the water table (this is called SVE).

AS/SVE systems are used for contaminants that have a tendency to evaporate easily. The contaminants found in shallow groundwater are VOCs and evaporate easily.

AS is accomplished through a series of injection wells that are drilled to below the water table. These wells are placed every 60 feet or less to be effective. Air piping must run from an air compressor to each injection well. The SVE wells are similar although they are not drilled to below the water table. Soil vapors are purged from the SVE wells and treated at a treatment plant located on the ground surface. Treatment plants may treat the vapors using carbon adsorption or burning (incineration, catalytic oxidation). The treatment plant and air compressors will be located throughout the area to be treated.

5.2.5 Phytoremediation

Phytoremediation uses living plants to clean up or remediate sites by removing pollutants from the soil and water. Plants help remove and possibly break down some pollutants, including the solvents found in Zone 4 OU-2 shallow groundwater.

Trees—most commonly poplar trees—are the types of plant most often used for treatment of groundwater contamination. Tree roots grow down to near the water table and withdraw contaminated groundwater. Once in the tree, the pollutants may be degraded in the root zone or released to the atmosphere.

Typically, phytoremediation is most effective at cleaning up shallow groundwater sites with low to moderate levels of contaminants, since roots have a limited penetration depth. Phytoremediation can be a visually pleasing approach for clean up. A disadvantage of phytoremediation includes time for the trees to reach maturity. Upon planting, the root system does not extend to the groundwater. Root system growth into the aquifer is necessary to promote destruction of the contaminants.

Phytoremediation seems to be a promising technology to help prevent pollutants from spreading into the San Antonio River.

5.2.6 Anaerobic Cometabolic Bioremediation (Enhanced Microorganism Breakdown)

Enhanced microorganism breakdown (or biodegradation) is a treatment process for groundwater contamination. Enhanced biodegradation uses naturally occurring microorganisms (bacteria) to degrade, or break down, hazardous substances into less toxic or nontoxic substances. Microorganisms, just like humans, digest organic substances for nutrients and energy.

To speed up the natural breakdown of fuels or solvents, technologies are available that help create favorable environmental conditions for the microorganisms to digest the contaminants. For chlorinated solvents, two types of enhanced biodegradation can be used: aerobic cometabolism and anaerobic reductive dehalogenation. With aerobic cometabolism, other organic compounds (such as methane or propane) are injected into the groundwater along with oxygen to accelerate the biodegradation of the chlorinated solvents. The microorganisms digest and grow using the added organic compounds. They digest the chlorinated solvents when the added organic compounds are gone.

With anaerobic reductive dehalogenation, more complex organic compounds (e.g., vegetable oil or molasses) are added without oxygen. The microorganisms digest the complex organics and use up any remaining oxygen. Under these conditions, the microorganisms may respire (“breathe”) the chlorinated solvents, since oxygen is not present. The chlorine atoms are removed from the chlorinated compounds in steps and the eventual result is harmless ethene. However, during the process, byproducts may accumulate from TCE degradation; these include DCE and vinyl chloride. The byproducts themselves will eventually be degraded.

To be effective, both enhanced biodegradation processes require that relatively large amounts of the organic supplements be injected into the ground. Injection wells typically must be placed very closely (e.g., every 25 feet or less). The organic compounds must be re-injected every six months, and the entire process can take up to two years to complete.

Methane or propane (aerobic cometabolism) injection was not considered feasible because of public safety issues and low probability of success. Therefore, the alternatives developed in Section 6.0 consider the use of vegetable oil (anaerobic cometabolism) for enhancing natural biodegradation processes.

5.2.7 Monitored Natural Attenuation

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The NCP, the regulatory framework for the Superfund program, defines natural attenuation as a process that “will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem.” MNA involves sampling, active monitoring, modeling and evaluating contaminant reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

5.2.7.1 Biodegradation

Biodegradation is considered the primary destructive process that acts to reduce contaminant concentrations. CAH biodegradation can occur via three mechanisms: reductive dechlorination, electron donor reactions and cometabolism. Of these, reductive dechlorination is the most important process for the biodegradation of chlorinated solvents (e.g., TCE) under typical groundwater conditions.

The term reduction is used for any chemical reaction that adds electrons to an element. Reductive dechlorination is a process by which anaerobic microorganisms dechlorinate the CAHs while metabolizing other sources of organic carbon that serve as the microorganisms primary substrate (i.e., food). The organic carbon that serves as the primary growth substrate may consist of naturally occurring organic matter or anthropogenic material such as fuel hydrocarbons.

During the metabolism of the primary substrate, electrons are generated. For metabolism to continue an electron acceptor is required and a certain mass of electron acceptor is needed to support biodegradation of a corresponding mass of primary substrate. Dechlorination of the CAHs occurs when the CAH is used as an electron acceptor (i.e., electrons are added to the CAH) and a chlorine atom in the molecule is replaced with a hydrogen atom.

A variety of electron acceptors can be used by microorganisms during biodegradation of the primary substrate including, dissolved oxygen, nitrate, ferric iron, sulfate, and carbon dioxide. Because the microorganisms derive much more energy in the biodegradation process when dissolved oxygen and nitrate are the electron acceptors (relative to CAHs), CAHs are generally not utilized as an electron acceptor until these thermodynamically favored electron acceptors are consumed. While reductive dechlorination can occur under a range of conditions, the most rapid rates of biodegradation resulting from reductive dechlorination occur when oxygen and nitrate are depleted or absent and sulfate and/or carbon dioxide are available as the electron acceptor.

Reductive dechlorination results in the sequential dechlorination of CAHs: PCE is dechlorinated to TCE, which is dechlorinated to DCE, which is dechlorinated to vinyl chloride, which is dechlorinated to ethene. The products of partial dechlorination of the parent CAHs (e.g., vinyl chloride) are more susceptible to other biodegradation processes (most notably biodegradation under aerobic conditions) than the more highly chlorinated parent CAH.

The rate at which biodegradation occurs is affected by several factors including the amount of primary substrate present and the amount of oxygen and other electron acceptors present in the groundwater system.

Kelly AFB contracted HydroGeoLogic Inc. (HGL), in 1999 to produce a series of groundwater and chemical transport models aimed at evaluating the corrective measures alternatives presented in this CMS document. **Table 5.3** presents the biodegradation half-lives previously calculated for Site S-4 (a source area) and for the Zone 4 off-base plumes. A detailed account of the HGLs modeling process for the Zone 4 CMS may be found in the attached document (Appendix A). The Expanded Basewide Ground-Water Flow Model and Its Application For Simulation of Zone 4 Remediation Options at Kelly AFB, Texas (HGL, 2001).

TABLE 5.3
Biodegradation Half-Lives in Years for PCE, TCE, 1,2-DCE, and Vinyl Chloride
Zone 4 Technical Evaluation of Corrective Measures Alternatives, Kelly Air Force Base, Texas

Chlorinated Compound	Site S-4		Zone 4 Offbase
	Breakthrough Curve Analysis		
	Method of Buscheck & Alcantar (1995)	Visual Inspection of Linearly Plotted Values	
PCE	2.3-3.0	2-4	8
TCE	2.4-3.0	2-4	6
1,2-DCE	NVC	3	8
Vinyl Chloride	NVC	2	1

As shown in **Table 5.3**, higher biodegradation rates (i.e., shorter half-lives) were calculated for Site S-4 than for the Zone 4 plume. This is because at Site S-4, groundwater conditions are generally anaerobic (i.e., oxygen is depleted or absent) and a fuel spill of BTEX constituents is presumed to serve as primary substrate (i.e., food) for the microorganisms. In Zone 4, on the other hand, the groundwater system is presumed to be transitional to aerobic. Additionally, there appears to be an absence of both naturally occurring and/or man-made carbon sources to act as primary substrate for microorganism growth.

5.2.7.2 Dispersion

Dispersion (also referred to as hydrodynamic dispersion) is the process by which a contaminant plume spreads out from the main direction of groundwater flow. Dispersion results in reduced contaminant concentrations in the main plume, but may introduce contaminants into relatively pristine portions of the aquifer cross gradient and downgradient from the direction of groundwater flow. Two very different processes cause hydrodynamic dispersion: mechanical dispersion and molecular diffusion. Mechanical dispersion is the dominant mechanism causing hydrodynamic dispersion at normal groundwater velocities. At extremely low groundwater seepage velocities, molecular diffusion can become an important mechanism, but molecular diffusion is generally ignored for most groundwater studies.

Molecular Diffusion

Molecular diffusion occurs when concentration gradients cause solutes to migrate from zones of higher concentration to zones of lower concentration. This will occur as long as a concentration gradient is present, even if there is no hydraulic gradient to create groundwater flow. Again, molecular diffusion is important only at low groundwater seepage velocities and is not considered to be an important process in the Zone 4 plumes.

Mechanical Dispersion

Mechanical dispersion is the mixing that occurs as a result of local variations in the groundwater velocity field. With time, a given volume of solute gradually will become more dispersed as different portions of the mass are transported at the differing velocities. In general, the main cause of variations of both rate and direction of transport velocities is the heterogeneity of the porous medium. These heterogeneities are present at scales ranging from microscopic (e.g., pore to pore) to macroscopic (e.g., well to well) to megascopic (e.g., a regional aquifer system).

Mechanical dispersion is described by the following relationship:

$$\text{Mechanical dispersion} = \alpha_x v_x$$

Where α_x is the dispersivity [L] and v_x is the average seepage velocity of groundwater [L/T]. *Dispersivity* is a parameter that is characteristic of the porous medium through which the contaminant migrates. Dispersivity represents the spreading of a contaminant over a given length of flow, and therefore has units of length.

Numerous field studies have been performed to quantify dispersivty, the most comprehensive of which is a compilation presented by Gelhar et al. 1992. Gelhar et al. suggest, reasonable estimates for dispersivity in the x or longitudinal direction (i.e., the principle direction of groundwater flow) between 1 and 20 with the greater values associated with the most heterogenous porous media. In the y or lateral direction, Gelhar et al. suggests using ratios ranging from 1/5 to 1/20 of the assigned longitudinal value with 1/5 representing the most heterogenous porous media. In the z or vertical direction, Gelhar et al. suggests using a value that is 100 times smaller than the lateral (y direction) dispersivity value.

The groundwater system in Zone 4 is heterogenous and significant variation in groundwater flow velocity may be expected. Considering the heterogeneous nature of the groundwater system in Zone 4, HGL input conservative longitudinal and lateral dispersivity values of 15 feet and three feet, respectively (HGL, 2001), into the expanded basewide model.

5.2.7.3 Dilution

Dilution can be defined as entry into the groundwater system of water made available via recharge. Dilution defined in this manner may therefore represent recharge to the groundwater system and generally includes precipitation that infiltrates through the vadose zone and water entering the groundwater system via discharge from surface water bodies (e.g., streams and lakes). Recharge of a groundwater system has two effects on the natural attenuation of a dissolved contaminant plume. Additional water entering the system due to infiltration of precipitation or from surface water will contribute to dilution of the plume, and the influx of relatively fresh, electron-acceptor-charged water may alter geochemical processes.

In some cases, this additional water may provide an influx of electron acceptors potentially increasing the overall electron-accepting capacity within the contaminant plume. Such a shift may be beneficial for biodegradation for compounds used as electron donors, such as fuel hydrocarbons or vinyl chloride. However, these shifts can also make conditions less favorable for reductive dechlorination.

In addition to the inorganic electron acceptors that may be dissolved in the recharge (e.g., dissolved oxygen, nitrate, or sulfate), the introduction of water with different geochemical properties may foster geochemical changes in the aquifer.

Evaluating the effects of dilution can be difficult because dispersivity, sorption and biodegradation are often not well quantified and separating out the effects of dilution may be very difficult indeed.

5.2.7.4 Sorption

Sorption is the process in which contaminants partition from the groundwater and cling to a solid surface. Many organic contaminants, including the chlorinated organics found in the Zone 4 groundwater plume, are removed from solution by sorption onto the soil. Sorption of contaminants onto the solid matrix results in slowing (retardation) of the contaminant relative to the average flow velocity of groundwater and a reduction in dissolved contaminant concentrations in groundwater.

The sorption process is a complex phenomenon caused by several mechanisms (i.e., London-vander Walls forces, Coulomb forces, hydrogen bonding, ligand exchange, covalent bonding, dipole forces, and hydrophobic forces). The result of the various sorption processes is described by the retardation factor (R) that represents the difference between the velocity of groundwater and that of the contaminant. The retardation factor is defined as:

$$R = \frac{V_x}{V_c} = 1 + \left(\ell / n\right) x \left(f_{oc}\ x\ K_{oc}\right)$$

Where:

The ratio v_x/v_c describes the relative velocity between the groundwater and the dissolved contaminant.

ℓ is the bulk density
n is porosity
f_{oc} is the fraction of organic carbon
K_{oc} is the organic carbon/water partition coefficient

Examination of this equation shows that the retardation factor varies depending upon the fraction of organic carbon contained within the soil, porosity of the media, and the chemical-specific organic carbon/water partitioning coefficient. The higher the retardation factor, the greater the sorption and thus the greater the solute movement is retarded.

Table 5.4 presents the calculated retardation factors used in the development of the expanded basewide groundwater flow and contaminant transport model (HGL, 2001).

TABLE 5.4
Retardation Factors for PCE, TCE, 1,2-DCE, and Vinyl Chloride
Zone 4 Technical Evaluation of Corrective Measures Alternatives, Kelly Air Force Base, Texas

Chlorinated Compound	Organic Carbon/Water Partitioning Coefficient (Koc)	Retardation Factor	Reference for K_{oc}
PCE	364	1.3	Pankow and Cherry, 1996
TCE	126	1.1	Pankow and Cherry, 1996
1,2-DCE	86	1.1	Pankow and Cherry, 1996
Vinyl Chloride	2.5	1.0	Montgomery and Welkom, 1990

Notes:
Bulk density = 1.7 g/cm^3
Porosity = 30% or 0.30
F_{oc} = 158 mg/Kg or 0.0158%

The calculated retardation factors range from 1.3 for PCE to 1.0 for vinyl chloride. These calculated values indicate the sorption process is expected to be most effective in slowing (retarding) the movement of PCE while vinyl chloride is expected to travel at essentially the same rate as groundwater flow.

5.2.7.5 Volatilization

Although not a destructive natural attenuation process, volatilization does remove contaminants from groundwater. Partitioning of a contaminant between the liquid phase and the gaseous phase is governed by Henry's Law. Thus the Henry's Law constant of a chemical determines its tendency to volatilize from groundwater into the soil gas. Henry's Law states that the concentration of a contaminant in the gaseous phase is directly proportional to the compound concentration in the liquid phase and is a constant characteristic of the compound. Stated mathematically, Henry's Law is given by (Lyman et al., 1992).

$$C_a = HC_l$$

Where: C_a = concentration in air (atm)
H = Henry's Law constant (atm • m^3/mol)
C_l = concentration in water (mol/m^3)

Henry's Law constants for chlorinated and petroleum hydrocarbons range over several orders of magnitude.

With the exception of vinyl chloride, the physiochemical properties of chlorinated solvents give them low Henry's Law constants. There is typically only a small surface area of the groundwater flow system exposed to soil gas and volatilization of chlorinated solvents from groundwater is a relatively slow process. Because of this, the impact of volatilization on dissolved contaminant reduction can generally be assumed to be negligible. VOC concentrations were measured in five soil vapor monitoring wells and five groundwater monitoring wells located within the Zone 4 off-base area. Soil vapor monitoring wells were installed adjacent to groundwater monitoring wells that have had detectable concentrations of vinyl chloride in the groundwater. Soil gas samples were collected from a depth of five feet bgs and were considered representative of vapor concentrations at the source of contamination.

Concentrations of VOCs measured in soil gas samples were considerably below the screening levels developed for the Zone 4 OU-2 off-base area. Results of modeling efforts alone indicated that most COPCs identified in groundwater were not likely to migrate through the soil column into indoor air at concentrations resulting in significant estimates of risk. The results of the modeling effort combined with the results of the soil gas sampling effort clearly showed that none of the VOCs in the shallow groundwater (including vinyl chloride) could migrate into indoor air to yield significant risk estimates. (*Draft Final Human Health Risk Assessment*, June 2001, ITIR Zone 4 OU-2 and S-4 Soil Vapor Monitoring, CH2M HILL, March 2000.)

5.3 Lines of Evidence Demonstrating Natural Attenuation

The demonstration that natural attenuation processes are active requires multiple lines of evidence. Primary lines of evidence may include direct observations including the presence of daughter products and declining concentration trends in parent and daughter concentrations. Secondary lines of evidence may include geochemical footprints indicating indirectly the type of process occurring that will result in the destruction of COCs.

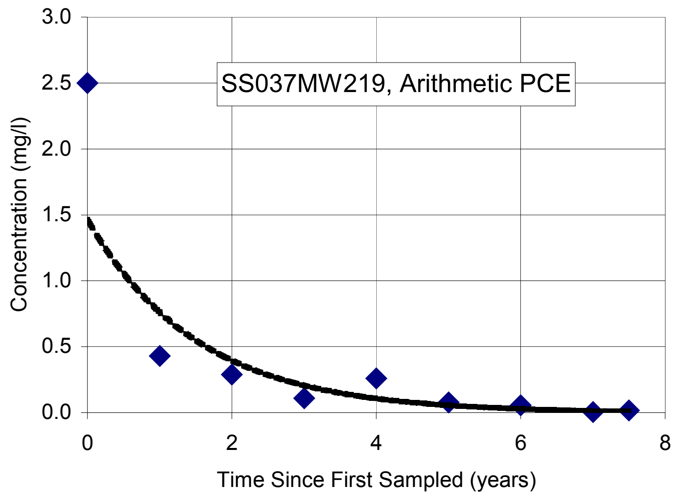
Primary Lines of Evidence

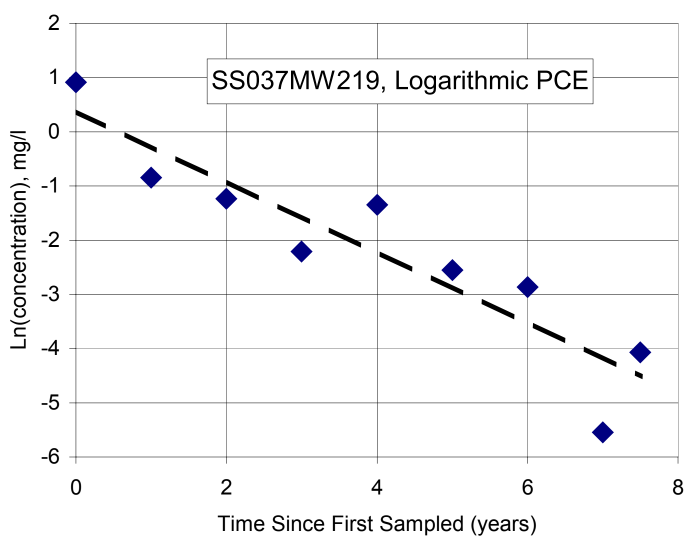
Appendix B contains time and distance plots of concentration trends of parent compounds and daughter products. The trend plots were prepared from groundwater samples collected along the centerlines of SS051 and MP plumes from permanent monitoring wells. Figure B-1 shows the wells selected to approximate the centerlines of the two plumes.

The graphs below are examples of the arimethic plot of concentration versus time at a single well showing the exponential decay curve. The second graphic shows the semi-logarithmic plot of the same data illustrating the linear decay trend. The concentration decay with time illustrates the loss of contaminant from the various attenuation mechanisms discussed above. The example well is located downgradient of the MP source area with the initial sample being collected in 1994. Partial containment of the source area was in progress at that time with a series of boundary line extraction wells. The slurry containment wall and optimized extraction well system were constructed in 1999. Similar plots for TCE, DCE and vinyl chloride are included in Appendix B for selected wells along the plume centerlines.

Statistical analyses may also be used to characterize a concentration trend as either increasing, decreasing or stable. One statistical approach is the Mann-Kendall trend analysis. Mann-Kendall is a nonparametric statistical method that uses paired comparisons of each event concentration to all previous data. The Mann-Kendall analysis results are included in Appendix B. Each statistical test follows the concentration versus time trend plot for the individual wells. The results of the statistical testing show that most of the wells in the plumes show a declining concentration at a 90 percent confidence level.

In addition to the concentration trends for wells in the SS051 and MP plumes, three wells from outside the plumes were added for comparison. Wells SS052MW195, SS052MW197 and SS052MW198 are located to the north of East Kelly and outside the plumes sourced by sites on East Kelly and MP. The trends for these wells are either stable or increasing in comparison to the downward trends from the wells in the referenced plumes.





Secondary Lines of Evidence

When in situ biodegradation of the CAHs occurs, chemical footprints should be present in the site observations (National Academy of Sciences, 2000). The footprint will vary depending on the degradation process, i.e., reductive dechlorination, cometabolism or electron donor reactions.

The working hypothesis for the SS051 and MP plumes is that reductive chlorination is actively working to reduce concentrations of the CAHs in the source areas and that cometabolism is working to decrease CAH concentrations in the majority of the plume downgradient of the two source areas (SS051 and MP).

Chemical footprint characteristics were plotted for the SS051 plume and MP plume along the centerline of each plume. The profiles include the released constituents (PCE and/or TCE), biodegradation byproducts (1,2-DCE and vinyl chloride) along with ORP, dissolved oxygen and dissolved managese concentrations. ORP can indicate locations of strongly reducing conditions that are conducive to reductive dechlorination. DO must be depleted in the aquifer for reductive dechlorination to take place. The mobilization of manganese occurs by the anerobic bacteria that use insoluble manganese from the aquifer matrix as an electron acceptor, thereby reducing the manganese and producing a soluble form of the metal. Whereas manganese-reducing bacteria are not known to directly degrade the CAHs, these bacteria are using other organic compounds as a primary substrate and may degrade the CAHs through fortuitous cometabolism.

Figure 5.1(a) shows the centerline profile of the SS051 plume. The RFI demonstrated that TCE and cis-1,2 DCE are the primary constituents released by Air Force activities at this site. The onbase part of the plume is nearly devoid of PCE. PCE does enter the plume beyond 2,000 feet from the source area, most likely from offsite sources. Between the source area and the nearest (638 feet) downgradient well there is a 60 percent reduction in TCE concentration. From 638 feet to about 10,000 feet there is little reduction in TCE concentration, perhaps due in part to the influx of PCE, which degrades to TCE. Between 10,000 and 18,000 feet downgradient, the concentration of PCE and TCE degrade to concentrations near the detection limits. The concentration of cis-1,2 DCE stabilizes beyond 15,000 feet because the compound is being added to the system as a result of the degradation of the higher chlorinated compounds. Vinyl chloride has been detected infrequently and at concentrations below 1 ug/L in the distal parts of the plume also indicating that there is degradation of the higher chlorinated CAHs in that part of the plume.

Figure 5.1(b) shows the relationship of ORP, DO and dissolved manganese along the SS051 plume centerline. The DO plot shows that there is little oxygen in this system and that the degradation processes are anerobic. The ORP shows that the groundwater is reducing, with the exception of a point located about 10,000 feet downgradient. Manganese is below background (about 340 ug/L) from the source to about 10,000 feet downgradient. Manganese concentrations increase between 10,000 and 18,000 feet downgradient. This increase in dissolved manganese supports the conclusion that there is active cometabolism of the CAHs in the distal part of the SS051 plume.

Figure 5.2(a) shows the CAH concentration profiles along the centerline of the MP plume. The source concentrations at MP were much higher that at SS051 as the result of the presence of DNAPL. Vinyl chloride is present in the MP plume from the source area to about 8,000 feet downgradient, indicating that reductive dechlorination is active in the plume. **Figure 5.2(b)** shows the ORP, DO and dissolved manganese concentrations. The decrease in CAH concentrations corresponds to an area of depressed DO and ORP that supports the conclusion of reductive dechlorination. From 1,500 to 10,000 feet the concentrations of PCE, TCE and VC continue to decline at a relatively steep slope. The cis-

1,2 DCE concentrations decrease at a lower rate because DCE is being added to the plume from the degradation of PCE and TCE.

Natural Attenuation Summary

Graphical and statistical analysis of the chemical conditions in the plumes from sites SS051 and MP show that whereas the COCs have spread about 20,000 feet (about four miles) from the source areas, natural processes are at work to reduce chemical concentrations. Biological processes are evident in both the source areas and in the broad dilute plumes that have resulted from the spread of the chemicals.

SECTION 6.0

Developing Corrective Measures Alternatives

In Section 3.0, the range of potentially applicable technologies was screened to identify the most feasible. Technologies retained after the screening process were selected for use in CMAs developed in this section.

Remediation of the MP source area, SS051 source area and the off-base plumes is considered the primary objective of CMAs. CMAs developed consider the direct application of technical solutions to these three areas. Remediating the sources should significantly decrease cleanup times in off-base areas.

Figures 6.1 and **6.2** show the study areas targeted for corrective action at source areas Site MP and Site SS051, respectively. **Figure 6.3** shows the study area of off-site impacts targeted for corrective action.

6.1 Development of Corrective Measures Alternatives

The descriptions of CMAs are based on conceptual designs using the following assumptions:

- The existing MP systems (slurry wall and pump and treat system) and Zone 4 perimeter containment system (pump and treat) are common elements of all CMAs.
- The components of the technologies (e.g., wells, treatment plants, etc.) are evenly spaced over the targeted areas. The distance between technology components was selected using site hydrogeological conditions, historical information and professional judgment.
- The proposed source controls are common elements of the off-base alternatives. The final proposed source areas (MP and SS051) will be contained to prevent them from sourcing the off-base plume.
- Groundwater pumping and injection rates are based on average values for hydraulic conductivity, saturated thickness and porosity over the entire study area.
- Natural attenuation is a common element of all CMAs.

6.1.1 Site MP

In 1995, a five well pump and treat system was installed at Site MP to prevent the off-site migration of contaminated groundwater. From 1997 to 1998, this five well system was evaluated and optimized. A more effective two well recovery system was designed and installed in March 1998. Since the optimized recovery system began operation, downgradient contaminant concentrations have decreased significantly.

A slurry wall (about 300 feet by 300 feet) was constructed between March 1999 and

December 1999 to enclose the DNAPL source and contaminated soil beneath the footprints of the former buildings. The slurry wall extends from the ground surface to the top of the Navarro Clay.

Although there appears to be some degree of hydraulic communication between groundwater inside and outside the wall, a pumping well inside the wall is able to maintain an inward gradient. Since March 1999, over 2,000 gallons of DNAPL have been removed from the site and properly disposed of off-base. **Figure 6.1** shows the location of the slurry wall and recovery wells.

6.1.2 Site SS051

Interim source-control measures for the Site SS051 plume have focused on preventing the contaminated groundwater from migrating off-site. The installation of horizontal and vertical recovery systems in March 1999, along the entire eastern and southern boundaries of East Kelly were also a part of the interim source control. Preliminary evaluation indicates these wells effectively create a hydraulic barrier for further off-base migration of contaminated groundwater originating from Site SS051; this system also, at least, partially captures the Site MP plume in the southern part of East Kelly.

The horizontal recovery system was started in July 2000 and is currently pumping about 450 gallons per minute (gpm). The groundwater is treated by a UVOX process in a treatment plant located in the southeast corner of East Kelly. The UVOX process destroys the CVOCs, and the treated groundwater is discharged through the NPDES permitted outfall to Six Mile Creek. The approximate locations of the horizontal wells are shown on **Figure 6.4**.

6.2 Corrective Measures Alternatives

Tables 6.1 and **6.2** present the corrective measures alternatives developed for the source areas and off-site plumes, respectively. In **Tables 6.1** and **6.2**, the technology components for each alternative are stated and described. The design components for developing estimated costs are also listed. Based on the technical review, the best CMA may be a combination of alternatives.

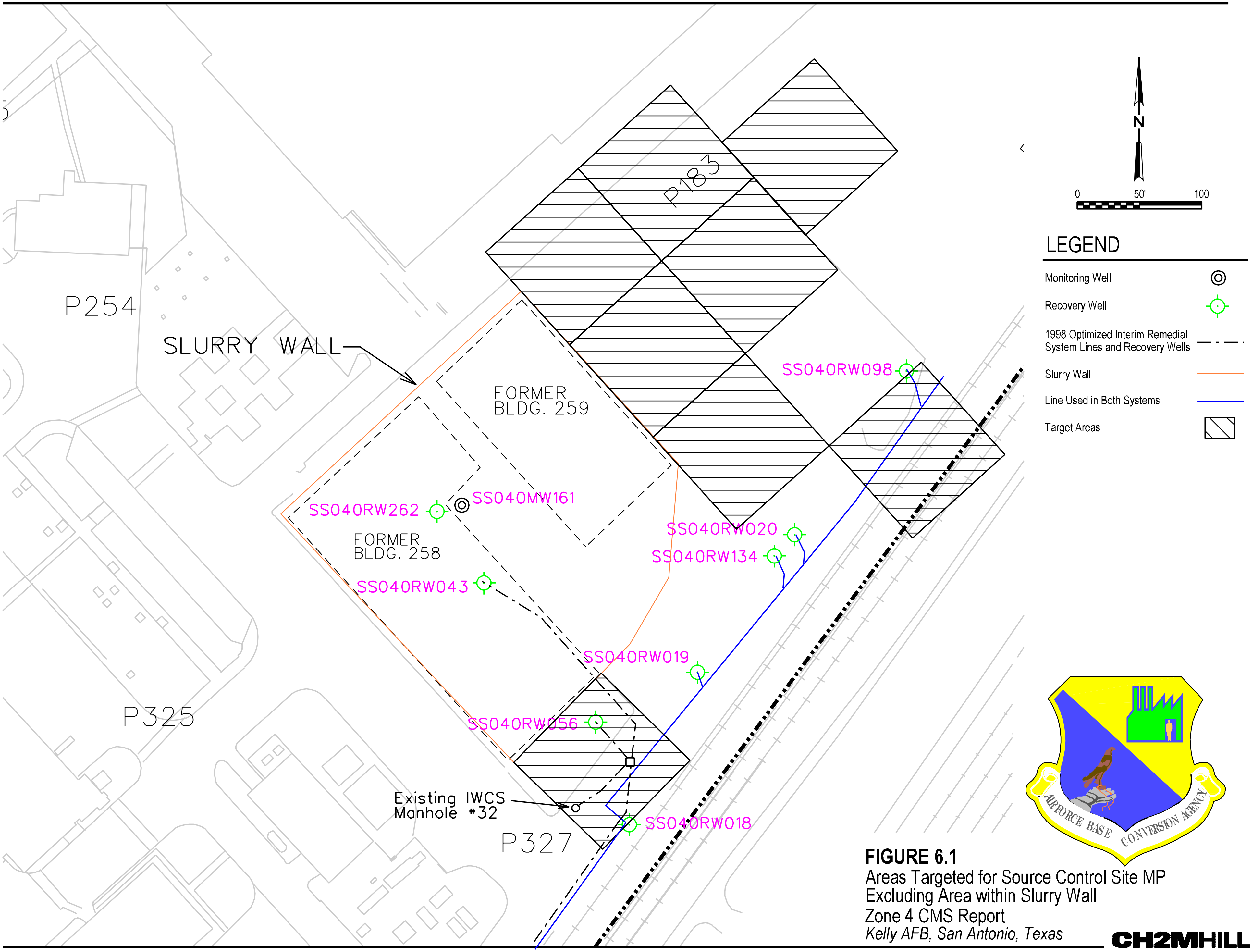


FIGURE 6.1
Areas Targeted for Source Control Site MP Excluding Area within Slurry Wall
Zone 4 CMS Report
Kelly AFB, San Antonio, Texas

CH2MHILL

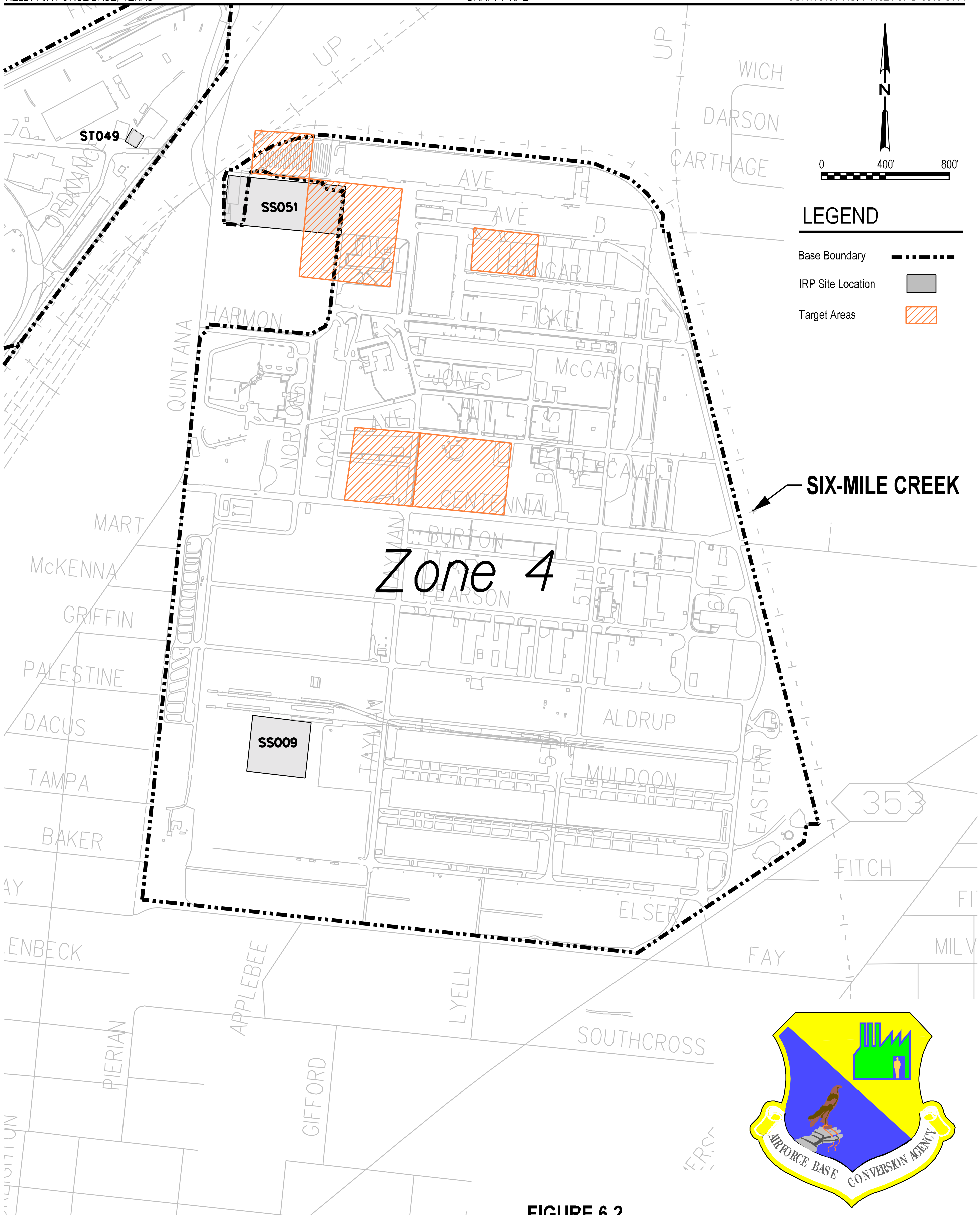


FIGURE 6.2
Areas Targeted for Source Control SS051
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

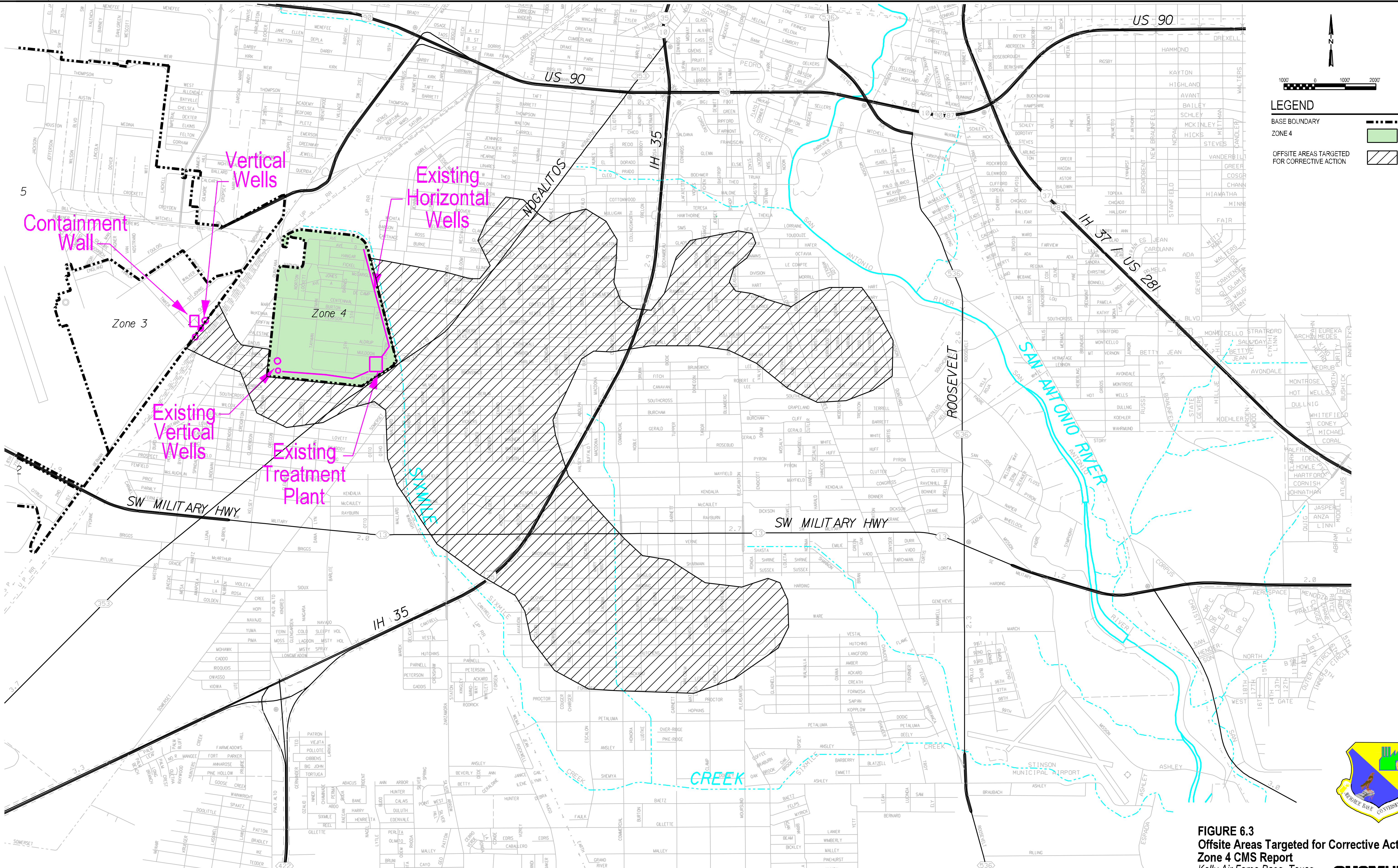


FIGURE 6.3
Offsite Areas Targeted for Corrective Action
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

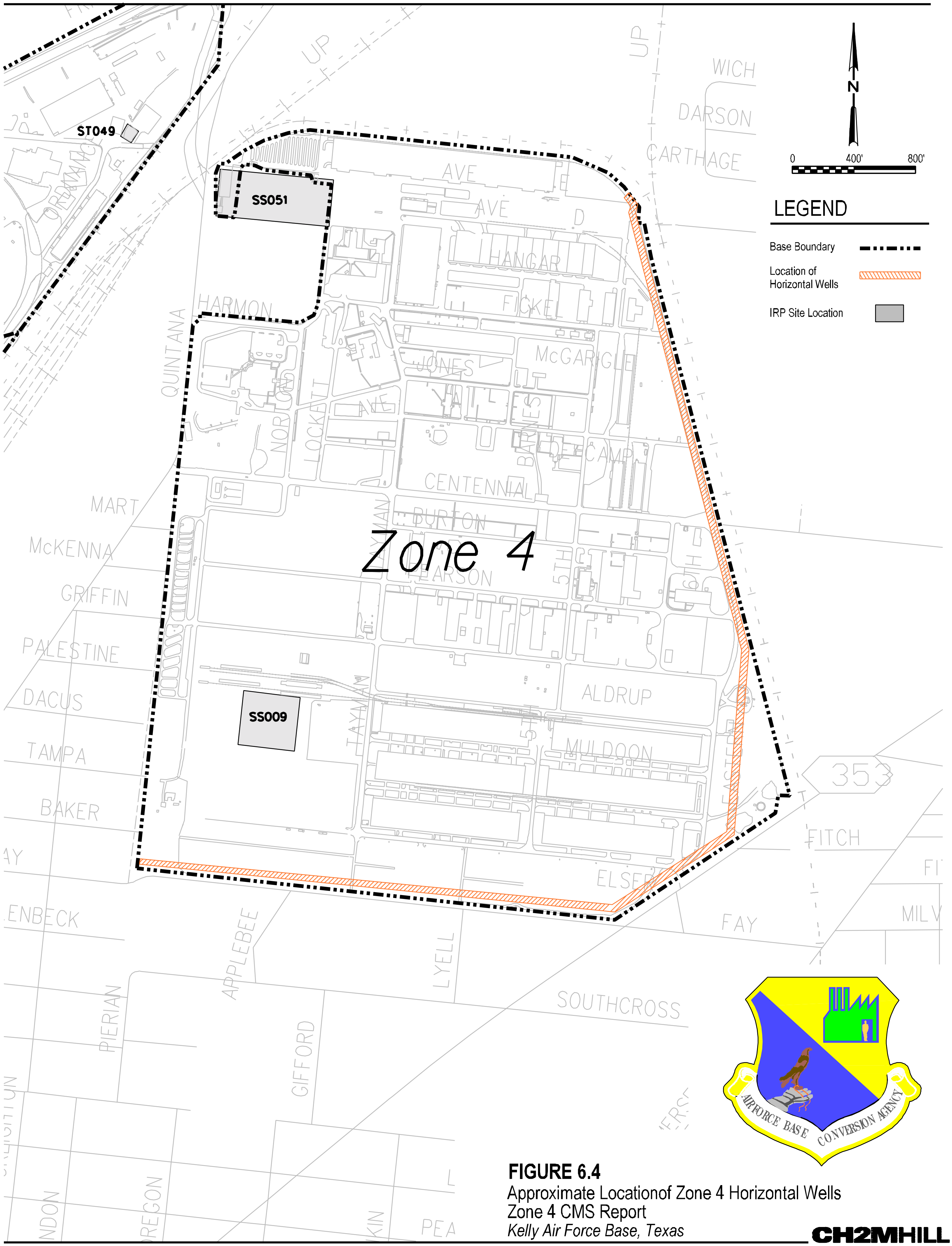


FIGURE 6.4
Approximate Locationof Zone 4 Horizontal Wells
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

TABLE 6.1
Corrective Measures Alternatives: Source Areas MP and SS051
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design components for costing
Alternative 1	Existing source control systems	The existing source control measures at Site MP include a slurry wall surrounding the entire Site MP source area and vertical extraction wells along the base perimeter between the Site MP source area and off base. Measures for the Site SS051 plume have focused on preventing the future off-site migration of the contaminated groundwater and include installing (March 1999) horizontal and vertical recovery systems along the entire eastern and southern boundaries of East Kelly. These wells effectively create a hydraulic barrier for further off-base migration of contaminated groundwater originating from Sites MP and SS051.	
	Treatment of extracted groundwater	Groundwater pumped from the horizontal and vertical well systems is treated to MCLs using UVOX technology. The treated groundwater is discharged through the NPDES permitted outfall to Six Mile Creek.	
Alternative 2	Existing source control measures with additional pump and treat	Placement of additional pump and treat systems using vertical wells would be performed to supplement existing source control systems. Vertical wells would be placed at the base of the shallow groundwater system directly above the Navarro Formation.	Vertical wells would be placed at the centers of the areas targeted for corrective action. The wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. At Site SS051 target areas, four wells are assumed placed. At Site MP, one well is assumed placed. Each vertical well is assumed to produce 15 gpm for a maximum groundwater withdrawal rate of about 86,400 gpd at Site SS051 and 21,600 gallons per day (gpd) at Site MP.

TABLE 6.1 CONTD.
Corrective Measures Alternatives: Source Areas SS051 and MP
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design components for costing
	Treatment and discharge of extracted groundwater	Groundwater pumped from the vertical well systems would be treated to MCLs (Table 4.2) using UVOX technology. Extracted groundwater would travel through extensive piping networks to aboveground treatment plants. Treated groundwater would be discharged to the storm sewer system or a surface water body (i.e., drainage channel).	It has been assumed that existing treatment plants are at capacity, therefore, construction of new treatment plants is assumed. One new aboveground treatment plant is assumed at Site SS051, and one new treatment plant is assumed at Site MP. Assume the location of the new treatment plants would be on base so lots for the treatment plants will not have to be purchased.
Alternative 3	Existing source control measures with flow-through reactive walls or Ferrox treatment zones	To supplement existing source control systems, reactive walls composed of zero valent iron (iron filings) will be installed. The reactive walls or treatment zones would be placed to the top of the Navarro Formation. The iron filings treat the contaminated groundwater by stripping off chlorine atoms from the solvents, converting them to harmless ethene.	At Site SS051, 400 feet of wall is assumed placed. At Site MP, 150 feet of wall is assumed placed. Placing the reactive walls would include constructing trenches to the top of the Navarro Formation assumed to be 40 feet bgs. Each trench would be two feet wide. The trenches would then be backfilled with 15 feet of iron filings and covered with native soils.
	Groundwater treatment and disposal	Treatment of the contaminated groundwater is accomplished in the subsurface by the flow-through reactive walls.	No additional aboveground treatment or water disposal than that currently in place would be required for this alternative.
Alternative 4	Existing source control measures with injection of flow-through reactive slurry	To supplement existing source control systems, reactive slurry composed of zero valent iron (ferrox) would be injected into the shallow groundwater system. Vertical wells would be used to inject the reactive slurry. The colloidal iron treats the contaminated groundwater by stripping off chlorine atoms from the solvents, converting them to harmless ethene.	Vertical wells would be placed evenly over the areas targeted for corrective action. The wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. At Site SS051 target areas, 44 wells are assumed placed. At Site MP, 15 wells are assumed placed.

TABLE 6.1 CONTD.
Corrective Measures Alternatives: Source Areas SS051 and MP
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design components for costing
	Groundwater treatment and disposal	Treatment of the contaminated groundwater is accomplished in the subsurface by the flow-through reactive slurry.	No additional aboveground treatment or water disposal than that currently in place would be required for this alternative.
Alternative 5	Existing source control measures with microorganism breakdown (enhanced biodegradation)	To supplement existing source control systems, vegetable oil would be injected into the shallow groundwater system. Vertical wells would be used to inject the vegetable oil. The vegetable oil enhances the naturally occurring biodegradation processes (anaerobic reductive dechlorination) treating the groundwater contamination. Injection would occur every six months to provide sufficient material for effective degradation of the contaminants.	Vertical wells would be placed evenly over the areas targeted for corrective action. The wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. At Site SS051, 400 wells are assumed placed. At Site MP, 66 wells are assumed placed.
	Groundwater treatment and disposal	The contaminated groundwater is treated in the subsurface by enhancing natural biodegradation processes.	No additional aboveground treatment or water disposal than that currently in place would be required for this alternative.
Alternative 6	Existing source control measures with oxygen treatment (*in situ* oxidation)	To supplement existing source control systems, potassium permanganate would be injected into the shallow groundwater system. Potassium permanganate was selected because it is considered safer to use than other oxidizing chemicals. Vertical wells would be used to inject the potassium permanganate. Aboveground piping networks would connect the injection wells to chemical storage/mixing tanks located in secure on-base areas. Each well would have one dedicated tank.	Vertical wells would be placed evenly over the areas targeted for corrective action. The wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. At Site SS051, 400 wells and 400 dedicated chemical storage/mixing tanks are assumed placed. At Site MP, 66 wells and 66 dedicated storage/mixing tanks are assumed placed.
	Groundwater treatment and disposal	The contaminated groundwater is treated in the subsurface by the oxidizing chemical.	No additional aboveground treatment or water disposal than that currently in place would be required for this alternative.

TABLE 6.1 CONTD.
Corrective Measures Alternatives: Source Areas SS051 and MP
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design components for costing
Alternative 7	Existing source control measures with air injection/vapor removal (AS/SVE)	To supplement existing source control systems, treatment of the contaminated water would be accomplished using a system of vertical air injection and vapor removal wells (AS/SVE). Extensive piping networks would connect the air injection wells to compressors located on the surface. Air would travel through this piping and be injected into the subsurface where it would bubble up through the shallow groundwater and volatilize contaminants (AS). The vapors would then be captured by the vapor removal wells (SVE). These captured vapors would travel through another extensive piping network to aboveground air treatment plants.	Air injection wells and SVE wells would be placed evenly over the areas targeted for corrective action. The wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. At Site SS051, 12 wells are assumed placed. At Site MP, three wells are assumed placed.
	Vapor treatment and discharge	Extracted vapors would be treated using granulated activated carbon that traps the contaminants. The treated air would then discharge directly to the atmosphere. Groundwater is treated *in situ* by the injected air volatilizing the contaminants.	Four new aboveground treatment plants are assumed at Site SS051, and one new treatment plant is assumed at Site MP. Assume the location of the new treatment plants would be on base so that lots for the treatment plants will not have to be purchased.

bgs below ground surface
gpd gallons per day
gpm gallons per minute
MCL maximum contaminant level

TABLE 6.2
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative A	Pump and treat plumewide	Plumewide (both Site SS051 and Site MP plumes) pump and treat system using horizontal or vertical wells placed at the base of the shallow groundwater system directly above the Navarro Formation.	Placement of 180 horizontal wells spaced every 1,000 feet or 3600 vertical wells placed every 50 feet. Depth of horizontal wells assumed to be 40 feet bgs. Well materials include 1,000 feet of slotted HDPE, and each horizontal well is assumed to produce 60 to 80 gpm, for a total maximum withdrawal rate of about 21 mgd of groundwater.
	River trench	Placement of a groundwater extraction trench with drain line system along the bank of the San Antonio River in the area of the SS051 Plume ZOD. The river trench would remove groundwater prior to reaching the San Antonio River, and extracted groundwater would be treated.	Trench assumed to be 2,000 feet long, 25 feet deep, with a slotted HDPE pipe placed at the base of the trench. Trench would be backfilled with 15 feet of gravel and then covered with native soils. The trench is assumed to produce 400 gpm, for a total of about 0.6 mgd of groundwater.
	Treatment and discharge of extracted groundwater	Groundwater pumped from the horizontal wells systems and the river trench would be treated to MCLs (Table 4.2) using UV/Ox technology. Extracted groundwater would travel through an extensive piping network to aboveground treatment plants. Treated groundwater would be discharged to the storm sewer system or a surface water body (i.e., drainage channel).	Treatment plant capacity assumed to be capable of treating extracted groundwater from approximately four horizontal wells (about 0.5 mgd). Assume there will be 45 aboveground treatment plants and that lots for the treatment plants will have to be purchased.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

TABLE 6.2 CONTD.
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative A1	Pump and treat plume-wide down the centerline of the plumes	Plumewide (both Site SS051 and Site MP plumes) pump and treat system using horizontal or vertical wells placed at the base of the shallow groundwater system. The wells would be located along the centerlines of the plumes in the troughs of the Navarro Clay surface. The centerlines of the plumes are generally the areas of thickest gravel that has filled the Navarro Troughs. In these areas, contaminant concentrations are highest.	Placement of 19 horizontal wells spaced every 2,400 feet or 380 vertical wells placed every 50 feet in the gravel-filled Navarro Troughs. Depth of horizontal or vertical wells assumed to be 40 feet bgs. Well materials include 1,000 feet of slotted HDPE. Each horizontal well is assumed to produce 60 to 80 gpm, for a total maximum withdrawal rate of about 2.2 mgd of groundwater.
	River trench	Placement of a groundwater extraction trench with drain line system along the bank of the San Antonio River in the area of the Site SS051Plume ZOD. The river trench would remove groundwater prior to reaching the San Antonio River. Extracted groundwater would be treated.	Trench assumed to be 2,000 feet long, 25 feet deep, with a slotted HDPE pipe placed at the base of the trench. Trench would be backfilled with 15 feet of gravel and then covered with native soils. The trench is assumed to produce 400 gpm, for a total of about 0.6 mgd of groundwater.
	Treatment and discharge of extracted groundwater	Groundwater pumped from the horizontal wells systems and the river trench would be treated to MCLs (Table 4.2) using UV/Ox technology. Extracted groundwater would travel through an extensive piping network to aboveground treatment plants. Treated groundwater would be discharged to the storm sewer system or a surface water body (i.e., drainage channel).	Treatment plant capacity assumed to be capable of treating extracted groundwater from approximately four horizontal wells (about 0.5 mgd). Assume there will be five aboveground treatment plants and that lots for the treatment plants will have to be purchased.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

TABLE 6.2 CONTD.
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative B	Limited pump and treat	Pump and treat system using horizontal or vertical wells placed at the base of the shallow groundwater system. The horizontal or vertical wells would be located specifically in those areas of the plumes where TCE and PCE concentrations are at or above 100 ppb.	Placement of six horizontal wells or 120 vertical wells spaced evenly in the areas of elevated TCE and PCE concentrations. Depth of wells assumed to be 40 feet bgs. Horizontal well materials include 1,000 feet of slotted HDPE. Each horizontal well is assumed to produce 60 to 80 gpm, for a total maximum withdrawal rate of about 0.7 mgd of groundwater.
	Phytoremediation along San Antonio River	Hybrid poplar trees would be planted along the bank of the San Antonio River in the area of the Site SS051Plume ZOD. The poplar tress would remove groundwater contamination prior to its reaching the San Antonio River. The trees would break down the contaminants. No groundwater is produced using this technology, which reduces aboveground treatment requirements.	Trees assumed planted along a 2,000-foot reach of the San Antonio River. The trees are assumed evenly-spaced every 25 feet. Four rows of trees would be planted for a total of 800 trees.
	Treatment and discharge of extracted groundwater	Groundwater pumped from the horizontal wells systems would be treated to MCLs (Table 4.2) using UV/Ox technology. Extracted groundwater would travel through an extensive piping network to aboveground treatment plants. Treated groundwater would be discharged to the storm sewer system or a surface water body (i.e., drainage channel).	Treatment plant capacity assumed to be capable of treating extracted groundwater from approximately four horizontal wells (about 0.5 mgd). Assume there will be two aboveground treatment plants and that lots for the treatment plants will have to be purchased.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

TABLE 6.2 CONTD.
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative C	Pump and treat plume-wide	Plumewide (both Site SS051 and Site MP plumes) pump and treat system using horizontal or vertical wells placed at the base of the shallow groundwater system directly above the Navarro Formation.	Placement of 180 horizontal wells or 3600 vertical wells spaced every 1,000 feet. Depth of wells assumed to be 40 feet bgs. Well materials include 1,000 feet of slotted HDPE. Each horizontal well is assumed to produce 60 to 80 gpm, for a total maximum withdrawal rate of about 21 mgd of groundwater.
	River trench	Placement of a groundwater extraction trench with drain line system along the bank of the San Antonio River in the area of the Site SS051 Plume ZOD. The river trench would remove groundwater prior to reaching the San Antonio River. Extracted groundwater would be treated.	Trench assumed to be 2,000 feet long, 25 feet deep, with a slotted HDPE pipe placed at the base of the trench. Trench would be backfilled with 15 feet of gravel and then covered with native soils. The trench is assumed to produce 400 gpm, for a total of about 0.6 mgd of groundwater.
	Treatment and Reinjection of extracted groundwater	Groundwater pumped from the horizontal wells systems and the river trench would be treated to MCLs (Table 4.2) using UV/Ox technology. Extracted groundwater would travel through an extensive piping network to aboveground treatment plants. Under this alternative, treated groundwater would travel through another extensive piping network to a system of horizontal injection wells.	Treatment plant capacity assumed to be capable of treating extracted groundwater from approximately four horizontal wells (about 0.5 mgd). Assume there will be 45 aboveground treatment plants and that lots for the treatment plants will have to be purchased. Under this alternative, a system of 180 horizontal injection wells would also be placed. Depth of horizontal injection wells assumed to be 40 feet bgs. Well materials include 1,000 feet of slotted HDPE. Each horizontal injection well is assumed to inject 60 to 80 gpm, for a total maximum injection rate of about 21 mgd of groundwater.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

TABLE 6.2 CONTD.
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative C1	Pump and treat plume-wide down the centerline of the plumes	Plumewide (both Site SS051 and Site MP plumes) pump and treat system using horizontal or vertical wells placed at the base of the shallow groundwater system. The wells would be located along the centerlines of the plumes in the troughs of the Navarro Clay surface. The centerlines of the plumes are generally the areas of thickest gravel that has filled the Navarro Troughs. In these areas, contaminant concentrations are highest.	Placement of 19 horizontal wells or 380 vertical wells spaced every 2,400 feet in the gravel-filled Navarro Troughs. Depth of wells assumed to be 40 feet bgs. Well materials include 1,000 feet of slotted HDPE. Each horizontal well is assumed to produce 60 to 80 gpm, for a total maximum withdrawal rate of about 2.2 mgd of groundwater.
	River trench	Placement of a groundwater extraction trench with drain line system along the bank of the San Antonio River in the area of the Site SS051 Plume ZOD. The river trench would remove groundwater prior to reaching the San Antonio River. Extracted groundwater would be treated.	Trench assumed to be 2,000 feet long, 25 feet deep, with a slotted HDPE pipe placed at the base of the trench. Trench would be backfilled with 15 feet of gravel and then covered with native soils. The trench is assumed to produce 400 gpm, for a total of about 0.6 mgd of groundwater.
	Treatment and Reinjection of extracted groundwater	Groundwater pumped from the horizontal wells systems and the river trench would be treated to MCLs (Table 4.2) using UV/Ox technology. Extracted groundwater would travel through an extensive piping network to aboveground treatment plants. Under this alternative, treated groundwater would travel through another extensive piping network to a system of horizontal injection wells.	Treatment plant capacity assumed to be capable of treating extracted groundwater from approximately four horizontal wells (about 0.5 mgd). Assume there will be aboveground treatment plants and that lots for the treatment plants will have to be purchased. Under this alternative, a system of 19 horizontal injection wells would also be placed. Depth of horizontal injection wells assumed to be 40 feet bgs. Well materials include 1,000 feet of slotted HDPE. Each horizontal injection well is assumed to inject 60 to 80 gpm, for a total maximum injection rate of about 2.2 mgd of groundwater.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

TABLE 6.2 CONTD.
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative D	Existing source control systems	The existing source control measures at Site MP include a slurry wall surrounding the entire Site MP source area and vertical extraction wells along the base perimeter between the Site MP source area and off base. Measures for the Site SS051 plume have focused on preventing the future off-site migration of the contaminated groundwater and include installing (March 1999) horizontal and vertical recovery systems along the entire eastern and southern boundaries of East Kelly. These wells effectively create a hydraulic barrier for further off-base migration of contaminated groundwater originating from Sites MP and SS051.	
	Treatment of extracted groundwater	Groundwater pumped from the horizontal and vertical well systems is treated to MCLs (Table 4.2) using UV/Ox technology. The treated groundwater is discharged through the NPDES permitted outfall to Six Mile Creek.	
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

TABLE 6.2 CONTD.
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative E	Flow-through reactive walls plumewide or ZVI slurry treatment zones	Plumewide (both Site SS051 and Site MP plumes) treatment would be performed by placing reactive walls or injected slurry treatment zones composed of zero valent iron (iron filings) to the top of the Navarro Formation. The iron filings act to strip off chlorine atoms from the solvents, converting them to harmless ethene.	Placement of nine reactive walls spaced every 5,000 feet. Trenches would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each trench would be 1,000 feet long and 2 feet wide. The trenches would then be backfilled with 15 feet of iron filings and covered with native soils. Injecting a ZVI slurry would require boring injection points every 20 to 30 feet along each line. The injections would treat approximately a 20 to 30 radius around each injection point.
	Flow-through reactive wall along the San Antonio River	Placement of a reactive wall or treatment zone composed of zero valent iron along the bank of the San Antonio River in the area of the Site SS051 Plume ZOD. The reactive wall would treat groundwater contamination prior to its reaching the San Antonio River. No groundwater is produced using this technology reducing aboveground treatment requirements.	A trench would be constructed to the top of the Navarro Formation assumed to be 25 feet bgs. This trench would be 1,000 feet long and 2 feet wide. The trench would then be backfilled with 15 feet of iron filings and then covered with native soils. Injecting a ZVI slurry would require boring injection points every 20 to 30 feet. The injections would treat approximately a 20 to 30 radius around each injection point.
	Groundwater treatment and disposal	Treatment of the contaminated groundwater is accomplished in the subsurface by the flow-through reactive walls.	No aboveground treatment plants or water disposal issues.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

TABLE 6.2 CONTD.
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative E1	Flow-through reactive walls or ZVI treatment zones plumewide down the centerline of the plumes	Plumewide (both Site SS051 and Site MP plumes) treatment would be performed by placing reactive walls or injected slurry composed of zero valent iron (iron filings) to the top of the Navarro Formation. The reactive walls or treatment zones would be located along the centerlines of the plumes in the troughs of the Navarro Clay surface. The centerlines of the plumes are generally the areas of thickest gravel that has filled the Navarro Troughs. In these areas, contaminant concentrations are highest.	Placement of 11 reactive walls spaced every 4,800 feet. Trenches would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each trench would be 1,000 feet long and 2 feet wide. The trenches would then be backfilled with 15 feet of iron filings and covered with native soils. Injecting a ZVI slurry would require boring injection points every 20 to 30 feet. The injections would treat approximately a 20 to 30 radius around each injection point.
	Flow-through reactive walls or treatment zones along the San Antonio River	Placement of two reactive walls composed of zero valent iron along the bank of the San Antonio River in the area of the Site SS051 Plume ZOD. The reactive walls or treatment zones would treat groundwater contamination prior to its reaching the San Antonio River. No groundwater is produced using this technology reducing aboveground treatment requirements.	Two trenches would be constructed to the top of the Navarro Formation assumed to be 25 feet bgs. These trenches would be 1,000 feet long and 2 feet wide. The trenches would then be backfilled with 15 feet of iron filings and covered with native soils. Injecting a ZVI slurry would require boring injection points every 20 to 30 feet. The injections would treat approximately a 20 to 30 radius around each injection point.
	Groundwater treatment and disposal	Treatment of the contaminated groundwater is accomplished in the subsurface by the flow-through reactive walls.	No aboveground treatment plants or water disposal issues.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

TABLE 6.2 CONTD.
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative F	Limited number of flow-through reactive walls or treatment zones	Treatment would be performed by placing reactive walls or injected slurry composed of zero valent iron (iron filings) to the top of the Navarro Formation. The reactive walls or treatment zones would be located specifically in those areas of the plumes where TCE and PCE concentrations are at or above 100 ppb.	Placement of four reactive walls spaced evenly in the areas of elevated TCE and PCE concentrations. Trenches would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each trench would be 2,500 feet long and 2 feet wide. The trenches would then be backfilled with 15 feet of iron filings and covered with native soils. Injecting a ZVI slurry would require boring injection points every 20 to 30 feet. The injections would treat approximately a 20 to 30 radius around each injection point.
	Groundwater treatment and disposal	Treatment of the contaminated groundwater is accomplished in the subsurface by the flow-through reactive walls.	No aboveground treatment plants or water disposal issues.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.
Alternative G	Limited microorganism breakdown (enhanced biodegradation)	Treatment (anaerobic reductive dechlorination) would be performed by injecting vegetable oil into the shallow groundwater system in those areas of the plumes where TCE and PCE concentrations are at or above 100 ppb. Injection would occur every six months to provide sufficient material for effective degradation of the contaminants.	Placement of 3,500 vertical injection wells on a 50-foot grid would be performed to cover the areas of elevated TCE and PCE concentrations. The injection wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing.
	Groundwater treatment and disposal	Treatment of the contaminated groundwater is accomplished in the subsurface through enhanced biodegradation processes.	No aboveground treatment plants or water disposal issues.

1 **TABLE 6.2 CONTD.**
2 Corrective Measures Alternatives: Off-Site Plumes
3 *Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas*

Alternative Name	Technology Components	Descriptions	Design Components for Costing
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.
Alternative H	Limited oxygen treatment (*in situ* oxidation)	Treatment (*in situ* oxidation) would be performed by injecting potassium permanganate into the shallow groundwater system in those areas of the plumes where TCE and PCE concentrations are at or above 100 ppb. Potassium permanganate was selected since it is considered safer to use than other oxidizing chemicals. Aboveground piping networks would connect the injection wells to chemical storage and mixing tanks located in secure buildings. Each well would have one dedicated tank.	Placement of 90 horizontal injection wells on a 100-foot grid would be performed to cover the areas of elevated TCE and PCE concentrations. Depth of horizontal wells assumed to be 40 feet bgs. Well materials include 1,000 feet of slotted HDPE.
	Groundwater treatment and disposal	Contaminated groundwater is treated in the subsurface through enhanced biodegradation processes.	No aboveground treatment plants or water disposal issues. However, storage/mixing tanks are required for the potassium permanganate. Assume there will be 90 aboveground storage/mixing tanks and they will be in secure buildings with aboveground piping connecting the tanks to the injection wells. Assume the lots for the storage/mixings tanks will have to be purchased.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

TABLE 6.2 CONTD.
Corrective Measures Alternatives: Off-Site Plumes
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Alternative Name	Technology Components	Descriptions	Design Components for Costing
Alternative I	Limited air injection/vapor removal (air sparging/SVE)	Contaminated water is treated using a system of vertical air injection and vapor removal wells (AS/SVE). The air injection/vapor removal wells would be located specifically in those areas of the plumes where TCE and PCE concentrations are at or above 100 ppb. Extensive piping networks would connect the air injection wells to compressors located on the surface. Air would travel through this piping and be injected into the subsurface where it would bubble up through the shallow groundwater and volatilize contaminants (air sparging). The vapors would then be captured by the vapor removal wells (SVE). These captured vapors would travel through another extensive piping network to aboveground air treatment plants.	Air injection wells would be placed every 60 feet and vapor extraction wells would be placed every 100 feet for a total of 5,000 vertical wells to cover the areas of elevated TCE and PCE concentrations. The wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing.
	Vapor treatment and discharge	Extracted vapors would be treated using granulated activated carbon that traps the contaminants. The treated air would then discharge directly to the atmosphere. Groundwater is treated *in situ* by the injected air volatilizing the contaminants.	Assume there will be ten aboveground treatment plants and lots for the treatment plants will have to be purchased.
	Monitored natural attenuation	MNA uses natural process to reduce concentrations. Concentrations may be reduced by biodegradation, dispersion, dilution, sorption, and volatilization. Monitoring wells would be sampled and groundwater analyzed for PCE, TCE, cis-1,2-DCE, vinyl chloride, and a suite of natural attenuation indicator parameters (e.g., nitrate, sulfate, dissolved oxygen, etc.).	Includes the construction of 25 new monitoring wells. The monitoring wells would be constructed to the top of the Navarro Formation assumed to be 40 feet bgs. Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing. Annual monitoring of 125 wells included.

bgs	below ground surface	MCL	maximum contaminant level	Ox	oxidation
DCE	dichloroethene	mgd	million gallons per day	PCE	tetrachloroethene
gpm	gallons per minute	NPDES	National Pollution Discharge Elimination System	ppb	parts per billion
HDPE	high-density polyethylene				

SECTION 7.0

Evaluating Corrective Measures Alternatives

This section describes the evaluation criteria, then presents the evaluation results for the CMAs developed and presented in Section 6.0. As mentioned throughout this CMS, the AFBCA is taking an innovative and interactive approach to identifying the best remedial alternative to clean up the Zone 4 off-base solvent plumes. The typical regulatory approach to choosing a CMA schedules public involvement near the end of the process. In this case, AFBCA has included the public early on in the process.

7.1 Evaluation Criteria

The CMAs were assessed by how well they comply with the four community concerns that have been established and the five technical standards for evaluation as presented in the EPA recommended approach for conducting RCRA Corrective Actions (EPA, 1994).

7.1.1 Community Concerns

The community concerns are defined in detail below in the following four paragraphs.

1. **Health concerns.** The CMAs were evaluated relative to protecting human health. This included looking at increased health risks resulting from things such as injection of oxidizing chemicals, intensity of construction efforts, and the effectiveness of the technology to cleanup the contaminants in the shallow groundwater.
2. **Property values.** The community would like to see minimal impacts on property values during construction and operation of the CMAs.
3. **Neighborhood disruption.** The community would like to see minimal disruption to the neighborhood during the construction and operation of a corrective measures alternative. In the short term, extensive construction activities, such as trenching, constructing treatment plants, and installing monitoring, extraction, and injection wells, will cause numerous traffic disruptions and noise impacts. In the long term, installed systems would require operation and maintenance activities such as the replacement and/or repair of treatment system components, sampling activities and required inspection and maintenance of the equipment.
4. **Cleanup time.** The community would like to see cleanup conducted as quickly as possible while also meeting other concerns and issues. Each corrective measures alternative was modeled and the project operational cleanup time was estimated. Additionally, design and construction time was added into the cleanup time to determine the total cleanup time to MCL required for each corrective measures alternative for the entire off-base areas affected by these plumes.

7.1.2 Technical Criteria

The technical criteria are defined in the remainder of this section.

1. **Protect human health and the environment.** The corrective measures alternatives will be evaluated based on their ability to protect human health and the environment. The ability of a corrective measures alternative to meet this criterion may or may not be independent of its ability to achieve the other standards. For example, a corrective measures alternative may protect the environment, but may not be able to attain the corrective action objectives. The Zone 4 Human Health Risk Assessment (CH2M HILL , 2001), and Ecological Risk Assessment (CH2M HILL, 2001) indicate no impacts to human health or the environment under current conditions.

2. **Attain corrective action objectives.** The corrective measure alternatives will be evaluated based on their ability to achieve corrective action objectives. These objectives are defined in **Table 7.1** of this document. Since there is some uncertainty with this evaluation, it will be qualitatively characterized. Another aspect of this criterion is the time frame to achieve the CAOs. Estimates of time frames for the corrective measure alternatives to achieve the CAOs are provided for the alternatives developed for the off-base plumes. These estimates are based on computer modeling of the 12 corrective measures alternatives developed for the off-base plumes.

3. **Control the source of releases.** This criterion deals with controlling releases of contamination from the source (the area where the contamination originated). The known source areas (Site MP and Site SS051) are on Kelly AFB and East Kelly, respectively.

4. **Comply with applicable standards for waste management.** This criterion deals with managing wastes derived from the corrective measures alternative. For example, this may include groundwater from the pump and treat operations. All the corrective measures alternatives will be designed to comply with all standards for waste management. Consequently, this criterion was not included in the detailed evaluation presented here.

5. **Other factors.** There are five other factors, described below, that are to be considered if a corrective measures alternative achieves all of the above four criteria.

   5a. **Long-term reliability and effectiveness.** The corrective measures alternatives will be evaluated based on their reliability and the impacts of the remedy's failure. In other words, a qualitative assessment will be made of the chances of the corrective measures alternative failing and the consequences of failure.

   5b. **Reduction in the toxicity, mobility, or volume of wastes.** Corrective measures alternatives containing technologies that reduce the toxicity, mobility, or volume of the contamination will generally be favored over those that do not. Consequently, a qualitative assessment of the ability of the corrective measures alternatives to achieve this will be made.

   5c. **Short-term effectiveness.** The corrective measures alternatives will be evaluated based on the risk they create during the implementation of the remedy. This is especially important in the residential areas that comprise most of Zone 4. Factors that will be considered include fire, explosion, exposure to hazardous substances, and potential increases in automobile accidents due to traffic disruptions.

5d. Implementability. The corrective measures alternatives will be evaluated for their implementability taking into account the following factors:

- **Constructability**, including the difficulty to construct the systems in the residential setting, the construction disturbances they will create, access to public and private property may be required, and required spacing of technology components (e.g., wells and reinjection systems).
- **Operability,** including the operational disturbances they may create.
- **Availability** of equipment and resources to implement the technologies making up the corrective measures alternative.

5e. Cost. A net present value of each corrective measures alternative will be developed. Estimates of potential cost are based on conceptual level CMA descriptions provided in Section 5.0 of this document. **Appendix C** provides additional details regarding development of the cost opinions. The information in the cost opinions was based on the best available information regarding the anticipated scope of the corrective measures alternatives. Changes in the cost elements may occur as a result of new information and data collected during the engineering design of the selected remedial alternative. The cost opinions presented here are order-of-magnitude cost opinions that are expected to be within -50/+100 percent of the actual project costs.

7.2 Evaluation of Corrective Measures Alternatives

7.2.1 No Action Baseline

The No Action Baseline consists of evaluating the plume with no CMA alternatives. The No Action Baseline is not considered as a CMA, but a tool to compare the effectiveness of each CMA against. The existing remedial systems are removed in the model, and the plume is modeled with no current or future CMA in operation to estimate the cleanup time. The estimated cleanup time with No Action is over 100 years.

7.2.2 MP Area

A detailed evaluation, criteria, and modeling of seven CMAs for the MP area located outside of the existing slurry wall to the technical criteria was conducted. Computer modeling cleanup time predictions were performed for each of the seven CMAs. This evaluation is presented in **Table 7.1**.

7.2.3 Site SS051 Source Area

A detailed evaluation, criteria, and modeling of seven CMAs for the Zone 4 Site SS051 was conducted. Computer modeling cleanup time predictions were performed for each of the seven CMAs. This evaluation is presented in **Table 7.1**.

7.2.4 Off-Site Plumes

Twelve CMAs were evaluated against the above criteria and computer modeling cleanup time predictions to identify the six most promising CMAs. The major criteria are listed on

Table 7.2. Computer modeling was conducted to estimate the cleanup times for each of the 12 CMAs. The area above MCLs was calculated based on current conditions. The 98-percent criteria was based on the fact that the remaining two percent was not in residential neighborhoods. While concentrations are above MCLs, over time all appear to be decreasing. The evaluation found six CMAs to be most promising at meeting the screening criteria. Results from the groundwater effort modeling (HGL, 2001) will be presented for the six most promising CMAs.

7.3 Groundwater Modeling of Corrective Measures Alternatives

7.3.1 Modeling Background

Kelly AFB contracted HydroGeoLogic Inc. (HGL) in 1999 to produce a series of groundwater and chemical transport models aimed at evaluating the CMAs presented in this report. The effort began by utilizing the basewide groundwater model developed by HGL in December 1997, and then further expanding upon it during the current effort by incorporating a significant amount of new geologic data collected between 1998 and 1999. A more detailed model domain was then extracted from the expanded basewide model and used to evaluate the CMAs presented in this report. A detailed account of the HGL modeling process for the Zone 4 CMS may be found in the attached document (**Appendix A**) The Expanded Basewide Ground-Water Flow Model and It's Application For Simulation of Zone 4 Remediation Options at Kelly AFB, Texas (HGL, 2001).

7.3.2 Model Set-Up

The following subsections will summarize the development of the groundwater model developed by HGL used to evaluate the corrective measures alternatives presented in this TECMA report.

7.3.2.1 Key Aspects of the Expanded Groundwater Model

The groundwater model simulations were developed using HGL proprietary modeling software which is based upon the widely accepted groundwater flow and solute transport code, MODFLOW, originally developed by the United States Geological Survey (USGS).

Key aspects of the expanded groundwater model used to evaluate the various CMAs include the following (HGL, 2001):

- It is composed of four model layers that represent vertical heterogeneity in the alluvial aquifer
- It simulates extraction wells, aquifer recharge, and groundwater flux entering and exiting the model domain

TABLE 7.1
Detailed Evaluation of Alternatives: Off-Site Plumes
Zone 4 Groundwater Corrective Measures Study, Kelly Air Force Base, Texas

Evaluation Standards	Alternative A	Alternative A1	Alternative B	Alternative C	Alternative C1	Alternative D	Alternative E	Alternative E1	Alternative F	Alternative G	Alternative H	Alternative I
	Pump-and-treat plumewide with river trench	Pump-and-treat plumewide down plume centerlines with river trench	Limited pump-and-treat with phytoremediation and MNA	Pump-and-treat plumewide, river trench, and reinjection of treated groundwater	Pump-and-treat plumewide down plume centerlines, river trench, and reinjection of treated groundwater	Existing source control systems and MNA	Flow-through reactive walls plumewide and along the San Antonio River	Flow-through reactive walls plumewide down plume centerlines and along the San Antonio River	Limited number of flow-through reactive walls and MNA	Limited microorganism breakdown (enhanced biodegradation) and MNA	Limited oxygen treatment (*In situ* oxidation) and MNA	Limited air injection/vapor removal (AS/SVE) and MNA
Protection of human health and the environment	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • The river trench should prevent groundwater from migrating into the San Antonio River.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • The river trench should prevent groundwater from migrating into the San Antonio River.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Phytoremediation at the river should prevent groundwater from migrating into the San Antonio River.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • The river trench should prevent groundwater from migrating into the San Antonio River.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • The river trench should prevent groundwater from migrating into the San Antonio River.	Protective of human health and moderately protective of the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Low concentration groundwater is seeping into the San Antonio River, so there maybe some risk to the environment.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • The reactive wall at the river should treat groundwater prior to flowing into the San Antonio River.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • The reactive wall at the river should treat groundwater prior to flowing into the San Antonio River.	Protective of human health and moderately protective of the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Low concentration groundwater is seeping into the San Antonio River, so there maybe some risk to the environment.	Protective of human health and moderately protective of the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Low concentration groundwater is seeping into the San Antonio River, so there maybe some risk to the environment.	Protective of human health and moderately protective of the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Low concentration groundwater is seeping into the San Antonio River, so there maybe some risk to the environment.	Protective of human health and moderately protective of the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Low concentration groundwater is seeping into the San Antonio River, so there maybe some risk to the environment.
Attain CAOs	Some uncertainty about the ability to achieve groundwater clean-up standards due to difficulty in capturing all contaminated groundwater and the potential for drawing contamination from other off-base sources into wells.	Some uncertainty about the ability to achieve groundwater clean-up standards due to difficulty in capturing all contaminated groundwater and the potential for drawing contamination from other off-base sources into wells.	Greater uncertainty about the ability to achieve groundwater clean-up standards due to difficulty in capturing all contaminated groundwater potential for drawing contamination from other off-base sources into wells, and the uncertain capabilities of the NA processes.	Some uncertainty about the ability to achieve groundwater clean-up standards due to difficulty in capturing all contaminated groundwater and the potential for drawing contamination from other off-base sources into wells.	Some uncertainty about the ability to achieve groundwater clean-up standards due to difficulty in capturing all contaminated groundwater and the potential for drawing contamination from other off-base sources into wells.	Greater uncertainty about the ability to achieve groundwater clean-up standards due to the potential for other off-base sources and the uncertain capabilities of the NA processes.	Some uncertainty about the ability to achieve groundwater clean-up standards due to unknown groundwater flushing rates and the potential for other off-base sources to provide contaminant flux to the treatment areas.	Some uncertainty about the ability to achieve groundwater clean-up standards due to unknown groundwater flushing rates and the potential for other off-base sources to provide contaminant flux to the treatment areas.	Some uncertainty about the ability to achieve groundwater clean-up standards due to unknown flushing rates, the potential for other off-base sources to provide contaminant flux to the treatment areas, and the uncertain capabilities of the NA processes.	Greater uncertainty about the ability to achieve groundwater clean-up standards due to unknown effectiveness of the microorganisms, the potential for other off-base sources, and the uncertain capabilities of the NA processes.	Greater uncertainty about the ability to achieve groundwater clean-up standards due to unknown effectiveness of the oxidation process, the potential for other off-base sources, and the uncertain capabilities of the NA processes.	Greater uncertainty about the ability to achieve groundwater clean-up standards due to unknown effectiveness of the air injection process, the potential for other off-base sources, and the uncertain capabilities of the NA processes.
Time frame to attain CAOs	• Design and construction time: Estimated to be from five to seven years. • Approximately 20 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from one to two years. • Approximately 14 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from one to two years. • Approximately 17 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from six to eight years. • Approximately 14 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from two to three years. • Approximately 14 years to achieve CAOs based on recent modeling.	• Design and construction time: 0 years (currently completed). • Approximately 18 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from three to five years. • Approximately 15 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from two to three years. • Approximately 15 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from one to two years. • Approximately 15 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from two to three years. • Approximately 18 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from two to three years. • Approximately 16 years to achieve CAOs based on recent modeling.	• Design and construction time: Estimated to be from two to three years. • Approximately 18 years to achieve CAOs based on recent modeling.

TABLE 7.1 CONTD.
Detailed Evaluation of Alternatives: Off-Site Plumes
Zone 4 Groundwater Corrective Measures Study, Kelly Air Force Base, Texas

Evaluation Standards	Alternative A	Alternative A1	Alternative B	Alternative C	Alternative C1	Alternative D	Alternative E	Alternative E1	Alternative F	Alternative G	Alternative H	Alternative I
Long-term reliability and effectiveness	Reliable: • These technologies are standard in the industry and, with proper maintenance, should remain effective for at least 20 years. • The consequences of the system failing are relatively minor (should not harm human health).	Reliable: • These technologies are standard in the industry and, with proper maintenance, should remain effective for at least 20 years. • The consequences of the system failing are relatively minor (should not harm human health).	Somewhat reliable: • The pump-and-treat technologies are standard in the industry and, with proper maintenance, should remain effective for at least 20 years. • Phytoremediation is a newer technology and is more prone to problems (trees not growing). • The consequences of the system failing are relatively minor (should not cause harm).	Somewhat reliable: • These technologies are standard in the industry and, with proper maintenance, should remain effective for at least 20 years. • Reinjection of groundwater may be problematic. • The consequences of the system failing are relatively minor (should not cause harm). If reinjection cannot be performed, it can be discharged to surface water.	Somewhat reliable: • These technologies are standard in the industry and, with proper maintenance, should remain effective for at least 20 years. • Reinjection of groundwater may be problematic. • The consequences of the system failing are relatively minor (should not cause harm). If reinjection cannot be performed, it can be discharged to surface water.	Reliable: • These technologies are standard in the industry and, with proper maintenance, should remain effective for at least 20 years. • The consequences of the system failing are relatively minor (should not cause harm).	Reliable: • Although reactive walls are relatively new to the industry, the existing data suggest that they should be reliable. They should be effective for at least ten years. At some point they may plug and need to be replaced. • The consequences of the system failing are relatively minor (should not cause harm), unless the walls plug up and cause mounding of groundwater and flooding.	Reliable: • Although reactive walls are relatively new to the industry, the existing data suggest that they should be reliable. They should be effective for at least ten years. At some point they may plug and need to be replaced. • The consequences of the system failing are relatively minor (should not cause harm), unless the walls plug up and cause mounding of groundwater and flooding.	Reliable: • Although reactive walls are relatively new to the industry, the existing data suggest that they should be reliable. They should be effective for at least ten years. At some point they may plug and need to be replaced. • The consequences of the system failing are relatively minor (should not cause harm), unless the walls plug up and cause mounding of groundwater and flooding.	Less reliable: • Enhancement of microorganisms is relatively new to the industry, so it is not clear how reliable it will be. • The consequences of the system failing are relatively minor (should not cause harm), unless failure results in the accumulation of vinyl chloride.	Less reliable: • *In situ* oxidation is relatively new to the industry, so it is not clear how reliable it will be. • The consequences of the system failing are relatively minor (should not cause harm), unless failure results in release of the oxidizing compounds into the environment.	Less reliable: • These technologies are standard in the industry and, with proper maintenance, should remain effective for at least 20 years. • The consequences of the system failing are relatively minor (should not cause harm), unless failure results in the migration of vapors into residences and ambient air.
Reduction in the TMV of wastes	Effective in reducing TMV: • Will capture and remove the contaminants. The groundwater treatment system will reduce their toxicity.	Effective in reducing TMV: • Will capture and remove the contaminants. The groundwater treatment system will reduce their toxicity.	Effective in reducing TMV: • Will capture and remove some of the contaminants. The groundwater treatment system will reduce their toxicity.	Effective in reducing TMV: • Will capture and remove the contaminants. The groundwater treatment system will reduce their toxicity.	Effective in reducing TMV: • Will capture and remove the contaminants. The groundwater treatment system will reduce the their toxicity.	Less effective in reducing TMV: • The existing system will capture and remove some of the contaminants. The groundwater treatment system will reduce the their toxicity.	Effective in reducing TMV: • The contaminants will be treated to harmless ethene by the reactive walls.	Effective in reducing TMV: • The contaminants will be treated to harmless ethene by the reactive walls.	Effective in reducing TMV: • The contaminants will be treated to harmless ethene by the reactive walls.	Less effective in reducing TMV: • Contaminants will be degraded in the areas influenced by the injected vegetable oil; however, due to heterogeneous geology, some areas may not be influenced.	Less effective in reducing TMV: • Contaminants will be degraded in the areas influenced by the injected potassium permanganate; however, due to heterogeneous geology, some areas may not be influenced.	Less effective in reducing TMV: • Contaminants will be volatilized in the areas influenced by the injected air; however, due to heterogeneous geology, some areas may not be influenced.

TABLE 7.1 CONTD.
Detailed Evaluation of Alternatives: Off-Site Plumes
Zone 4 Groundwater Corrective Measures Study, Kelly Air Force Base, Texas

Evaluation Standards	Alternative A	Alternative A1	Alternative B	Alternative C	Alternative C1	Alternative D	Alternative E	Alternative E1	Alternative F	Alternative G	Alternative H	Alternative I
Short-term effectiveness	Some risk during implementation: • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents. • Drilling fluids may reach the surface during construction. • This technology could bring contaminated water to the surface if a leak were to occur.	Some risk during implementation: • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents. • Drilling fluids may reach the surface during construction. • This technology could bring contaminated water to the surface if a leak were to occur.	Less risk during implementation: • Smaller scale will reduce the chances of an accident. • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents. • Drilling fluids may reach the surface during construction. • This technology could bring contaminated water to the surface if a leak were to occur.	Some risk during implementation: • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents. • Drilling fluids may reach the surface during construction. • This technology could bring contaminated water to the surface if a leak were to occur.	Some risk during implementation: • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents. • Drilling fluids may reach the surface during construction. • This technology could bring contaminated water to the surface if a leak were to occur.	Little or no risk during implementation: • Limited risk from sampling	Some risk during implementation: • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents. • Drilling fluids and harmful vapors may reach the surface during construction. • Trenching and excavation risks associated with this alternative.	Some risk during implementation: • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents. • Drilling fluids and harmful vapors may reach the surface during construction. • Trenching and excavation risks associated with this alternative.	Less risk during implementation: • Smaller scale will reduce the chances of an accident. • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents. • Drilling fluids and harmful vapors may reach the surface during construction. • Trenching and excavation risks associated with this alternative.	Some risk during implementation: • Large number of injection wells in a residential area will create risks of accidents. • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents. • Vinyl chloride may be created, which may result in some risk.	More risk during implementation: • Handling oxidizing agents creates risk of releases. • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents.	More risk during implementation: • Large number of injection/extraction wells in a residential area will create risks of accidents. • Vapors may not be completely captured, resulting in some risk if vapors accumulate in residences. • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Traffic disruptions may increase the number of accidents.

TABLE 7.1 CONTD.
Detailed Evaluation of Alternatives: Off-Site Plumes
Zone 4 Groundwater Corrective Measures Study, Kelly Air Force Base, Texas

Evaluation Standards	Alternative A	Alternative A1	Alternative B	Alternative C	Alternative C1	Alternative D	Alternative E	Alternative E1	Alternative F	Alternative G	Alternative H	Alternative I
Implementability	Very difficult to implement: • Could be difficult to implement due to private property access. • Construction equipment will cause noise and dust. • Trenching and drilling will require road closures and detours and could disrupt utilities. • Lots will have to be purchased to locate treatment plants. • Treatment plants produce moderate constant noise.	More difficult to implement: • Could be difficult to implement due to private property access. • Construction equipment will cause noise and dust. • Trenching and drilling will require road closures and detours and could disrupt utilities. • Lots will have to be purchased to locate treatment plants. • Treatment plants produce moderate constant noise.	Less difficult to implement: • Less private property access expected, but still required. • Construction limited to areas of higher concentrations. • Construction equipment will cause noise and dust. • Trenching and drilling will require road closures and detours and could disrupt utilities. • Treatment plants produce moderate constant noise.	Very difficult to implement: • Could be difficult to implement due to private property access. • Plugging of the reinjection wells may be a constant problem. • Construction equipment will cause noise and dust. • Trenching and drilling will require road closures and detours and could disrupt utilities. • Treatment plants produce moderate constant noise.	More difficult to implement: • Could be difficult to implement due to private property access. • Plugging of the reinjection wells may be a constant problem. • Construction equipment will cause noise and dust. • Trenching and drilling will require road closures and detours and could disrupt utilities. • Treatment plants produce moderate constant noise.	Easy to implement: • Few off-base construction disturbances. • Noise levels should be low.	Very difficult to implement: • Construction equipment will cause noise and dust. • Long, deep trenches will require road closures and detours and has the potential to disrupt utilities. • Maintenance of walls could include complete reconstruction. • Access to private and public land could be necessary.	More difficult to implement: • Construction equipment will cause noise and dust. • Long, deep trenches will require road closures and detours and has the potential to disrupt utilities. • Maintenance of walls could include complete reconstruction. • Access to private and public land could be necessary.	Difficult to implement: • Construction equipment will cause noise and dust. • Long, deep trenches will require road closures and detours and has the potential to disrupt utilities. • Maintenance of walls could include complete reconstruction. • Access to private and public land could be necessary.	Very difficult to implement: • Large number of injection wells in a residential area will cause significant disruptions. • Equipment causes noise and dust. • Drilling requires road closures and detours. • Construction could disrupt utilities. • Might be very difficult to gain access to all the private property.	Very difficult to implement: • Equipment causes noise and dust. • Drilling requires road closures and detours. • Construction could disrupt utilities. • Might be very difficult to gain access to all the private property. • Handling oxidizing chemicals will be challenging.	Very difficult to implement: • Large number of injection wells in a residential area will cause significant disruptions. • Equipment causes noise and dust. • Drilling requires road closures and detours. Construction could disrupt utilities. • Might be very difficult to gain access to all the private property. • Lots will have to be purchased to locate treatment plants. • Treatment plants. • Plant maintenance disruptions may be significant.
Cost												

AS air sparging
CAO corrective action objective
MNA monitored natural attenuation
NA natural attenuation
SVE soil vapor extraction
TMV toxicity, mobility, or volume

TABLE 7.2
Detailed Evaluation of Alternatives: Source Areas Site SS051 and Site MP
Zone 4 Groundwater Corrective Measures Study, Kelly Air Force Base, Texas

Evaluation Standards	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
	Existing source control systems	Existing source control systems with additional pump and treat	Existing source control systems with flow-through reactive walls	Existing source control systems with injection of reactive slurry	Existing source control systems with microorganism breakdown (enhanced biodegradation)	Existing source control systems with oxygen treatment (in situ oxidation)	Existing source control systems with air injection/vapor removal (AS/SVE)
Protection of human health and the environment	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Existing source control systems appear to be controlling migration of contaminants from the source area at Site MP and off site from Site SS051.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Supplementing existing source control systems is expected to provide increased control of contaminant migration from the source areas.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Supplementing existing source control systems with reactive walls is expected to provide for treatment of contaminants in the targeted areas.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Supplementing existing source control systems with reactive slurry is expected to provide for treatment of contaminants in the targeted areas.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Supplementing existing source control systems by enhancing biodegradation is expected to provide for treatment of contaminants in the targeted areas.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Supplementing existing source control systems by oxygen treatment is expected to provide for treatment of contaminants in the targeted areas.	Protective of human health and the environment: • The groundwater is currently not being used, so there is no current risk from groundwater consumption. Institutional controls are planned and should prevent future consumption of the groundwater. • Supplementing existing source control systems by AS/SVE is expected to provide for treatment of contaminants in the targeted areas.
Attain CAOs	Some uncertainty about the ability to achieve groundwater clean-up standards as stand-alone systems.	Some uncertainty about the ability to achieve groundwater clean-up standards due to difficulty in capturing all contaminated groundwater and the potential for drawing contamination from other sources into wells.	Some uncertainty about the ability to achieve groundwater clean-up standards due to unknown groundwater flushing rates and the potential for other sources to provide contaminant flux to the treatment areas.	Some uncertainty about the ability to achieve groundwater clean-up standards due to uncertainty in the ability to deliver the slurry to the contaminated zones, unknown effectiveness of the chemical processes, and the potential for other sources to provide contaminant flux to the treatment areas.	Some uncertainty about the ability to achieve groundwater clean-up standards due to unknown biodegradation rates, uncertainty in the ability to deliver the electron donor to the contaminated zones, and the potential for other sources to provide contaminant flux to the treatment areas.	Greater uncertainty about the ability to achieve groundwater clean-up standards due to unknown effectiveness of the oxidation process, uncertainty in the ability to deliver the chemicals to the contaminated zones, and the potential for other sources.	Greater uncertainty about the ability to achieve groundwater clean-up standards due to unknown effectiveness of the air injection process and the potential for other sources to provide contaminant flux to the treatment areas.
Time frame to attain CAOs	• Design and construction time: 0 years (currently completed). • Time to achieve CAOs has not been modeled.	• Design and construction time: Estimated to be from one to two years. • Time to achieve CAOs has not been modeled but is likely to be longer than the other alternatives. • Expected to decrease time needed to clean up off-base plumes.	• Design and construction time: Estimated to be from one to two years. • Time to achieve CAOs has not been modeled. • Expected to decrease time needed to clean up off-base plumes.	• Design and construction time: Estimated to be from one to two years. • Time to achieve CAOs has not been modeled but could be from one to two years. • Expected to decrease time needed to clean up off-base plumes.	• Design and construction time: Estimated to be from one to two years. • Time to achieve CAOs has not been modeled but could be from one to two years. • Expected to decrease time needed to clean up off-base plumes.	• Design and construction time: Estimated to be from one to two years. • Time to achieve CAOs has not been modeled, but could be from one to two years. • Expected to decrease time needed to clean up off-base plumes.	• Design and construction time: Estimated to be from two to three years. • Time to achieve CAOs has not been modeled but could be from two to three years. • Expected to decrease time needed to clean up off-base plumes.
Long-term reliability and effectiveness	Reliable: • These technologies are standard in the industry and, with proper maintenance, should remain effective for at least 20 years. • The consequences of the system failing could results in off-base release likely prolonging clean up time for off-base plumes.	Reliable: • These technologies are standard in the industry and, with proper maintenance, should remain effective for at least 20 years. • The consequences of the system failing are relatively minor (should not harm human health) since measures are supplements to existing systems.	Reliable: • Although reactive walls are relatively new to the industry, the existing data suggest that they should be reliable. They should be effective for at least ten years. At some point they may plug and need to be replaced. • The consequences of the system failing are relatively minor (should not cause harm), unless the walls plug up and cause mounding of groundwater and flooding.	Reliable: • Although reactive slurry injection is relatively new to the industry, the existing data suggest that it should be reliable. Slurry should be effective for at least ten years. • The consequences of the system failing are relatively minor (should not cause harm), unless the slurry plugs up and cause mounding of groundwater and flooding.	Less reliable: • Enhancement of microorganisms is relatively new to the industry, so it is not clear how reliable it will be. • The consequences of the system failing are relatively minor (should not cause harm), unless failure results in the accumulation of vinyl chloride.	Less reliable: • *In situ* oxidation is relatively new to the industry, so it is not clear how reliable it will be. • The consequences of the system failing are relatively minor (should not cause harm), unless failure results in release of the oxidizing compounds into the environment.	Less reliable: • These technologies are standard in the industry and, with proper maintenance, should remain effective for at least three years. • The consequences of the system failing are relatively minor (should not cause harm), unless failure results in the migration of vapors into structures or ambient air.

TABLE 7.2 CONTD.
Detailed Evaluation of Alternatives: Source Areas Site SS051 and Site MP
Zone 4 Groundwater Corrective Measures Study, Kelly Air Force Base, Texas

Evaluation Standards	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
Reduction in the TMV of wastes	Less effective in reducing TMV: • The existing systems capture and remove some of the contaminants. The groundwater treatment system will reduce the their toxicity.	Effective in reducing TMV: • Will capture and remove the contaminants. The groundwater treatment system will reduce their toxicity.	Effective in reducing TMV: • The contaminants will be treated to harmless ethene by the reactive walls.	Effective in reducing TMV: • The contaminants will be treated to harmless ethene by the reactive slurry; however, due to heterogeneous geology, some areas may not be influenced.	Less effective in reducing TMV: • Contaminants will be degraded in the areas influenced by the injected vegetable oil; however, due to heterogeneous geology, some areas may not be influenced.	Less effective in reducing TMV: • Contaminants will be degraded in the areas influenced by the injected potassium permanganate; however, due to heterogeneous geology, some areas may not be influenced.	Less effective in reducing TMV: • Contaminants will be volatilized in the areas influenced by the injected air; however, due to heterogeneous geology, some areas may not be influenced.
Short-term effectiveness	Little or no risk during implementation: • Limited risk from sampling.	Some risk during implementation: • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Drilling fluids may reach the surface during construction. • This technology could bring contaminated water to the surface if a leak were to occur.	Some risk during implementation: • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed. • Fluids and harmful vapors may reach the surface during construction. • Trenching and excavation risks associated with this technology.	Less risk during implementation: • Limited construction wastes (groundwater, soil, drilling fluids, and pavement) expected. • Some drilling fluids may reach the surface during construction; however, quantities not expected to be large.	Less risk during implementation: • Limited construction wastes (groundwater, soil, drilling fluids, and pavement) expected. • Some drilling fluids may reach the surface during construction; however, quantities not expected to be large.	More risk during implementation: • Handling oxidizing agents creates risk of releases. • Some drilling fluids may reach the surface during construction; however, quantities not expected to be large.	More risk during implementation: • Vapors may not be completely captured, which may result in some risk if vapors accumulate in residences. • Construction wastes (groundwater, soil, drilling fluids, and pavement) must be managed.
Implementability	Easy to implement: • Currently implemented.	More difficult to implement: • Additional treatment plants required, and these produce moderate constant noise. • Construction equipment will cause noise and dust. • Drilling could disrupt utilities.	More difficult to implement: • Construction equipment will cause noise and dust. • Long, deep trenches will require road closures and detours and has the potential to disrupt utilities. • Maintaining walls could include complete reconstruction.	Less difficult to implement: • Construction equipment will cause noise and dust. • Drilling could disrupt utilities.	Difficult to implement: • Construction equipment will cause noise and dust. • Drilling could disrupt utilities.	Difficult to implement: • Construction equipment will cause noise and dust. • Drilling could disrupt utilities. • Handling oxidizing chemicals will be challenging.	More difficult to implement: • Additional treatment plants required, and these produce moderate constant noise. • Construction equipment will cause noise and dust. • Drilling could disrupt utilities.
Cost							

AS air sparging
CAO corrective action objective
SVE soil vapor extraction
TMV toxicity, mobility, or volume

- It is calibrated to accurately represent slight changes in groundwater flow directions caused by seasonal fluctuations in water table elevations
- Utilizes hydraulic conductivity values estimated for all four model layers at more than 2,000 soil boring locations
- Accurately reproduces the groundwater pathways inferred from plume concentration contour maps presented in the Zone 4 RFI (CH2M HILL, 2001)
- Fate and Transport and Biodegradation rates
- Phase I modeling includes the source area turned on
- Phase II modeling includes the source area turned off

7.3.2.2 Model Input Parameters

Model input parameters include groundwater flow characteristics such as hydraulic conductivity, transmissivity, and effective porosity. Additional influences that must be accounted for as input into the groundwater model included the initial potentiometric surface, recharge to the local groundwater system, and groundwater flux (i.e. water budgets) both entering and exiting the model domain.

The model is composed of four (4) separate layers. The two uppermost layers (layers 1 and 2) are associated with the fine to moderate grained sediments generally linked with lower hydraulic conductivity values. The two lowermost layers (layers 3 and 4) are associated with coarse-grained sediments and correlated higher hydraulic conductivities. The top of the Navarro Clay formation represents the lower flow boundary beneath layer 4 of the model. Additional rationale used to delineate the vertical layering and structure of the expanded model included:

- Utilizing the entire saturated aquifer thickness above the Navarro Clay surface.
- Minimizing the vertical distortion of the numerical grid in order to reduce errors associated with calculating groundwater flow
- Maximizing the spatial resolution used to represent the heterogeneity of the saturated portion of the aquifer so that preferential groundwater flow pathways could be represented in the model
- Utilizing the upper several feet of the Navarro Clay in areas where it penetrates, or nearly penetrates, the surface of the water table in order to accurately define lateral hydraulic boundaries

Hydraulic Conductivity and Transmissivity

The distribution of hydraulic conductivity within the model varies both laterally and vertically due to the heterogeneity of the geologic system at and around Kelly AFB. Values for hydraulic conductivity incorporated in the expanded basewide model, from which the refined Zone 4 model was extracted, were estimated from a review of over 2,500 soil boring logs.

Lithologic components described on the soil boring logs were used to better constrain and calibrate the model. The methodology behind developing representative average hydraulic conductivity values involved using results from available slug and pumping tests conducted at Kelly AFB. A more detailed description outlining the process of developing hydraulic conductivity values may be found in the attached HGL report (HGL, 2001). **Table 7.3** presents the estimated mean hydraulic conductivity values for the most significant lithologic components based upon results from HGL basewide simulations (HGL, 2001). In general, layers 1 and 2 are associated with the fine to moderately-grained (low hydraulic conductivity) lithologies, and layers 3 and 4 are associated with the coarse grained (high hydraulic conductivity) lithologies.

TABLE 7.3
Estimated Mean Hydraulic Conductivity Values for the Major Lithologic Components
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Major Lithologic Units	Estimated Mean Hydraulic Conductivity (f/d)
Fill	62
Clay with sand lenses	21
Silt	20
Sand	33
Clayey gravel	95
Gravel	349

Figure 7.1 graphically presents the hydraulic conductivity of layers 3 and 4 that were generated by the calibrated expanded basewide model. These two layers represent approximately 85% of the saturated thickness within the model. Transmissivity, which is the product of the hydraulic conductivity and the saturated thickness of the shallow alluvial aquifer, is a measure of the amount of groundwater that can be transmitted horizontally through a unit width by the full saturated thickness of the aquifer under a hydraulic gradient. The transmissivity as calculated by the expanded basewide model is graphically presented in **Figure 7.2**.

Initial Potentiometric Surface

The initial potentiometric surface used in the expanded groundwater model was a composite set of water levels collected during March and April 1999. Water level data included the following:

- Groundwater elevations of approximately 1,000 monitoring wells collected during March and April 1999 as part of the 1999 Basewide Remedial Assessment (CH2M HILL, 2000)
- Groundwater elevations collected by SAIC as part of the April 1999 Site S-4 CMS investigation in Zone 3 at Kelly AFB

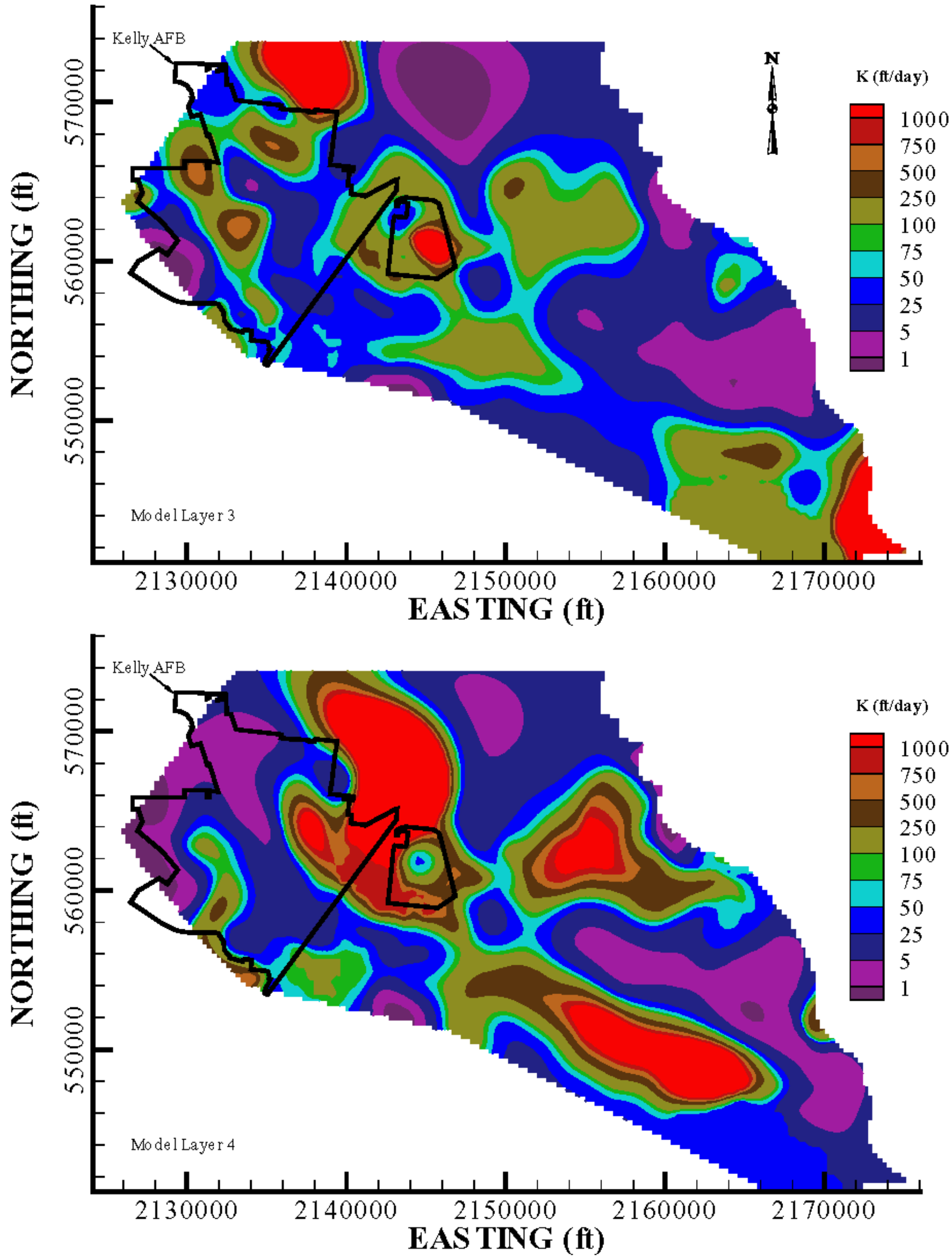


FIGURE 7.1
Hydraulic Conductivity of
Layers 3& 4
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

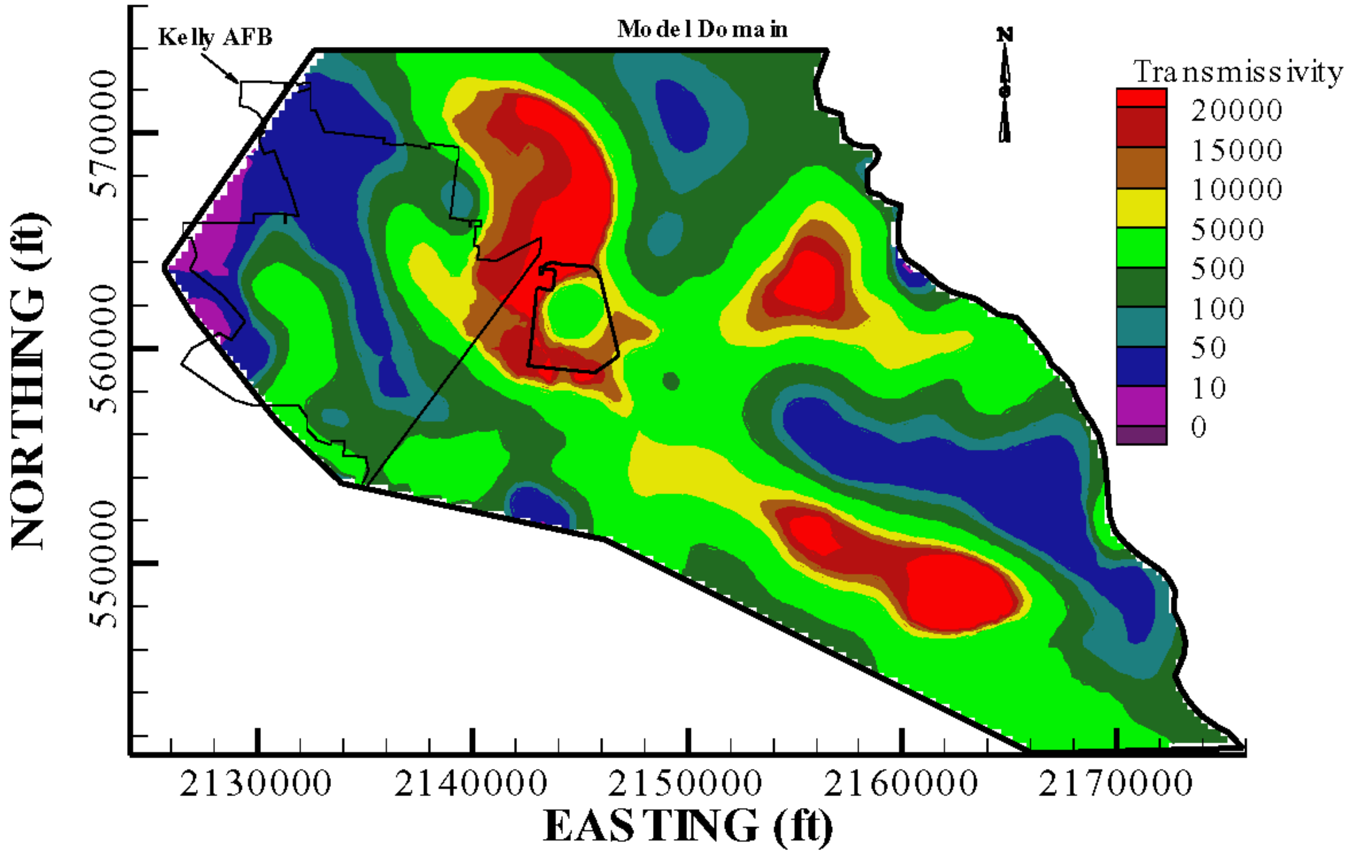


FIGURE 7.2

Transmissivity (f+ 2/day) Field Produced by the Expanded Basewide Model Calibration Simulated TCE Contours

Zone 4 Technical Evaluation CMAs
Kelly Air Force Base, Texas

- Supplemental groundwater elevations collected during the installation of 83 flight-augured soil borings as part of the Zone 4 RFI field investigation conducted by CH2M HILL. Seventy-three (73) were selected to augment the April 1999 water table data set.

These groundwater data were compiled and contoured using a data interpolation algorithms (Kriging) which takes into account spatial variance, location, and distribution (HGL, 2001).

Transport Model Parameters (Effective Porosity, Dispersivity, and Adsorption)

The three-dimensional distribution of effective porosity, dispersivity, and adsorption was evaluated in order to accurately simulate solute transport in saturated media. Their distribution is based upon the conceptual model developed from the characteristics of the shallow alluvial aquifer in the study area.

Porosity is defined as the percentage of voids contained within a unit body of the aquifer. Effective porosity represents that part of the porosity that is interconnected and capable of transmitting groundwater. The effective porosity of 30% used (HGL, 2001) represents an average of a range of values used at Kelly AFB before 1998. This value has led to reasonable estimates of the groundwater flow system and velocities.

Dispersivity describes the mixing of solute in groundwater by incorporating the effects of both molecular diffusion and mechanical dispersion. Molecular diffusion is the tendency for a solute in groundwater to move from an area of greater concentration toward an area of lesser concentration. This will occur as long as a concentration gradient is present, even if there is no hydraulic gradient to create groundwater flow. Mechanical dispersion is the result of mixing produced by groundwater and a solute traveling together through the aquifer matrix. In general, mechanical dispersion accounts for a larger part of the dispersivity than molecular dispersion. HGL accounted for the heterogeneous nature of the shallow aquifer at Kelly AFB and input longitudinal and lateral dispersivity values of 15 feet and 3 feet, respectively (HGL, 2001), into the expanded basewide model.

Adsorption is the process by which contaminants such as chlorinated solvents cling to a solid surface. This process can be represented by a value, the retardation factor, which represents the ratio between the total mass of solute to the mass of solute dissolved in the groundwater. The higher the retardation factor, the greater the adsorption and therefore the greater the solute movement is retarded compared to the groundwater flow. Retardation factors vary depending upon the amount of organic carbon contained within the soil, porosity, and the organic carbon/water partitioning coefficient. The organic carbon/water partitioning coefficient varies by individual contaminants. **Table 7.4** presents the retardation factors used to develop the expanded basewide model (HGL, 2001).

TABLE 7.4
Retardation Factors for PCE, TCE, 1,2-DCE, and Vinyl Chloride
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Chlorinated Compound	Retardation Factor	Organic Carbon/Water Partitioning Coefficient
PCE	1.3	364

TABLE 7.4 (CONTINUED)
Retardation Factors for PCE, TCE, 1,2-DCE, and Vinyl Chloride
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Chlorinated Compound	Retardation Factor	Organic Carbon/Water Partitioning Coefficient
TCE	1.1	126
1,2-DCE	1.1	86
Vinyl Chloride	1.0	2.5

7.3.2.3 Zone 4 Grid Boundary

In order to more accurately evaluate the proposed corrective measures alternatives, a model of the Zone 4 groundwater flow system was developed and refined from the expanded basewide model. **Figure 7.3** displays the model grid for the Zone 4 study area embedded within the expanded basewide model domain. The number of grid cells was increased in the refined Zone 4 model (**Figure 7.3**) in order to reduce numerical dispersion of the contaminant plume front (HGL, 2001) and provide a better simulation of the corrective measures alternatives within the study area. The numerical grid is made up of 109 rows and 173 cells for a total of 18,857 grid cells in each of the four model layers.

7.3.2.4 Transport Model Set-Up

Transport models were set-up to approximate the amount of time by which the various potential corrective measures alternatives could achieve the CAOs. Each transport simulation was run over two separate phases; an initial phase of 35 years followed by a second phase of 25 years. Concentration distributions were plotted at 5-year intervals. Specific components of the transport models that had to be developed included source terms for Site MP and Site SS051, the initial contaminant distribution, and biodegradation rates for the various remedial CMAs.

Source Terms

During the initial 35-year phase of each simulation, a source term was estimated and input into the two source areas (Sites MP and SS051). These source terms were on-going, but declined over the duration of the model simulation. **Table 7.5** presents the declining source terms and their duration within the model simulation (HGL, 2001).

TABLE 7.5
Phase 1 Estimated Source Terms for Transport Simulations
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Stress Period	Time (Years)	Period	Site MP Source PCE (μg/L)	Site SS051 Source TCE (μg/L)
1	10	2001-2010	1000	500
2	10	2011-2020	800	400
3	10	2021-2030	600	300
4	5	2031-2035	400	200

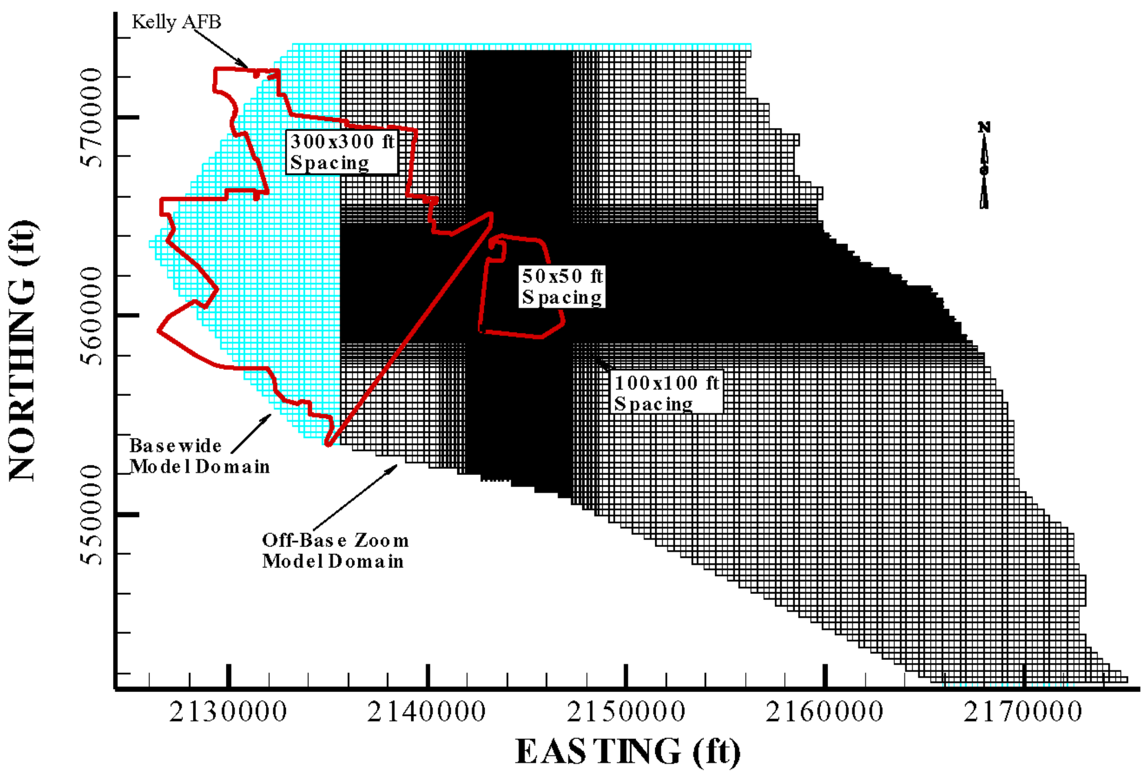


FIGURE 7.3
Zone 4 Model Grid Domain
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

Site MP was delineated as a 45,000 square foot area in Zone 3 at on-base Kelly AFB. Site SS051 was given a 10,000 square foot area near monitoring well SS004MW010 in the northwest corner of East Kelly. All source terms were applied to the three lowermost layers of the model (layers 2, 3, and 4) during the Phase I modeling, but the source terms were turned off during the Phase II modeling. The source terms were turned off to simulate containment of the sources by the MP slurry wall and Zone 4 pump and treat containment systems, as well as the proposed source control.

Initial Contaminant Distributions

AFBCA provided HGL with isoconcentration contour maps of PCE, TCE, 1,2-DCE, and vinyl chloride. The electronic files presented a combination of analytical data for groundwater samples collected during the 1999 Basewide Remedial Assessment (CH2M HILL, 2000) and other supplemental data collected by various contractors.

Biodegradation Rates

Biodegradation is the ability for microorganisms to breakdown dissolved organic contaminants. Applicable rates for biodegradation were developed for all relevant corrective measures alternatives. All bioenhancement options were simulated by attributing the rates to the model cells within the respective domain of each proposed CMA. The range of biodegradation rates were calculated based upon their relative effectiveness for each respective corrective measure alternative to degrade chlorinated solvents. **Table 7.6** presents the biodegradation rates for each pertinent option and their model cell specifications (HGL, 2001).

TABLE 7.6
Biodegradation Rates for Relevant Corrective Measures Alternatives
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Options	Cell Specifications	PCE	TCE	1,2-DCE	Vinyl Chloride
B	Phytoremediation along the San Antonio River	0.001	0.001	0.001	0.001
E, E1, F	Flow-through reactive walls	0.001	0.001	0.001	0.001
G	Microorganism breakdown	2	1.5	2	0.25
H	Oxygen treatment	1	0.75	1	.125
I	Air Injection/Vapor Removal	4	3	4	0.5

7.4 MP Area (Source Control) CMAs

Monitored Natural Attenuation (MNA) was considered a common element of all CMAs, since it is an ongoing, naturally occurring process. Additionally, the currently operating MP source control remedial system (slurry wall and pump and treat system) are common elements of all CMAs. Section 7.4.2 describes these existing source control systems as an alternative.

7.4.1 No Action Baseline

The No Action Baseline consists of evaluating the plume with no CMA alternatives. The No Action Baseline is not considered as a CMA, but a tool to compare the effectiveness of each CMA against. The existing remedial systems are removed in the model, and the plume is modeled with no current or future CMA in operation to estimate the cleanup time. The estimated cleanup time with No Action is over 100 years. The no action baseline is a regulatory requirement.

7.4.2 CMA 1: Existing Source Control Systems and Monitored Natural Attenuation

This CMA includes using the existing source control systems and MNA throughout the area. The current source control system at MP consists of a slurry wall around the known DNAPL, and two groundwater extraction wells at the base boundary. The area targeted for additional source control at the MP site consists of the area outside the slurry wall defined by the 100 ppb PCE contour. For costing purposes, this area has been divided into eight areas each 100 feet by 100 feet.

7.4.2.1 General Technology Description

The current source control systems at the MP Site consist of a slurry wall surrounding the entire MP Site source area and extraction wells along the base perimeter between the MP Site source area and off base. The current source control system at Zone 4 consists of horizontal and vertical extraction wells along its entire southern and eastern boundaries.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.4.2.2 Conceptual Design

The design and construction for the existing source treatment was completed in December 1999. In addition to these measures, this CMA would include MNA. A minimal amount of time would be required for designing and installing the additional monitoring wells since all other systems are already operational.

It has been assumed that four new monitoring wells would be installed (one for every two areas) and sampled annually for VOCs and natural attenuation indicator parameters. It has been assumed the new monitoring wells would be constructed of 20 feet of SS casing and 10 feet of SS screen.

7.4.2.3 Treatment and Disposal

Using CMA 1, extracted groundwater is currently being treated to the MCL standards using UVOX technology. The treated groundwater is being discharged to a surface water body, such as Leon Creek or Six-mile creek.

Because CMA 1 treats the contaminated water underground, there are no aboveground treatment plants, other than existing plants, and no additional water disposal issues.

7.4.3 CMA 2: Existing Source Control with Pump and treat

The area targeted for additional source control at the MP site consists of the area outside the slurry wall defined by the 100 ppb PCE contour. For costing purposes, this area has been divided into eight areas 100 feet by 100 feet. This CMA includes one vertical extraction for every four areas for a total of two vertical extraction wells. **Figure 7.4** provides a conceptual layout of this CMA.

7.4.3.1 General Technology Description

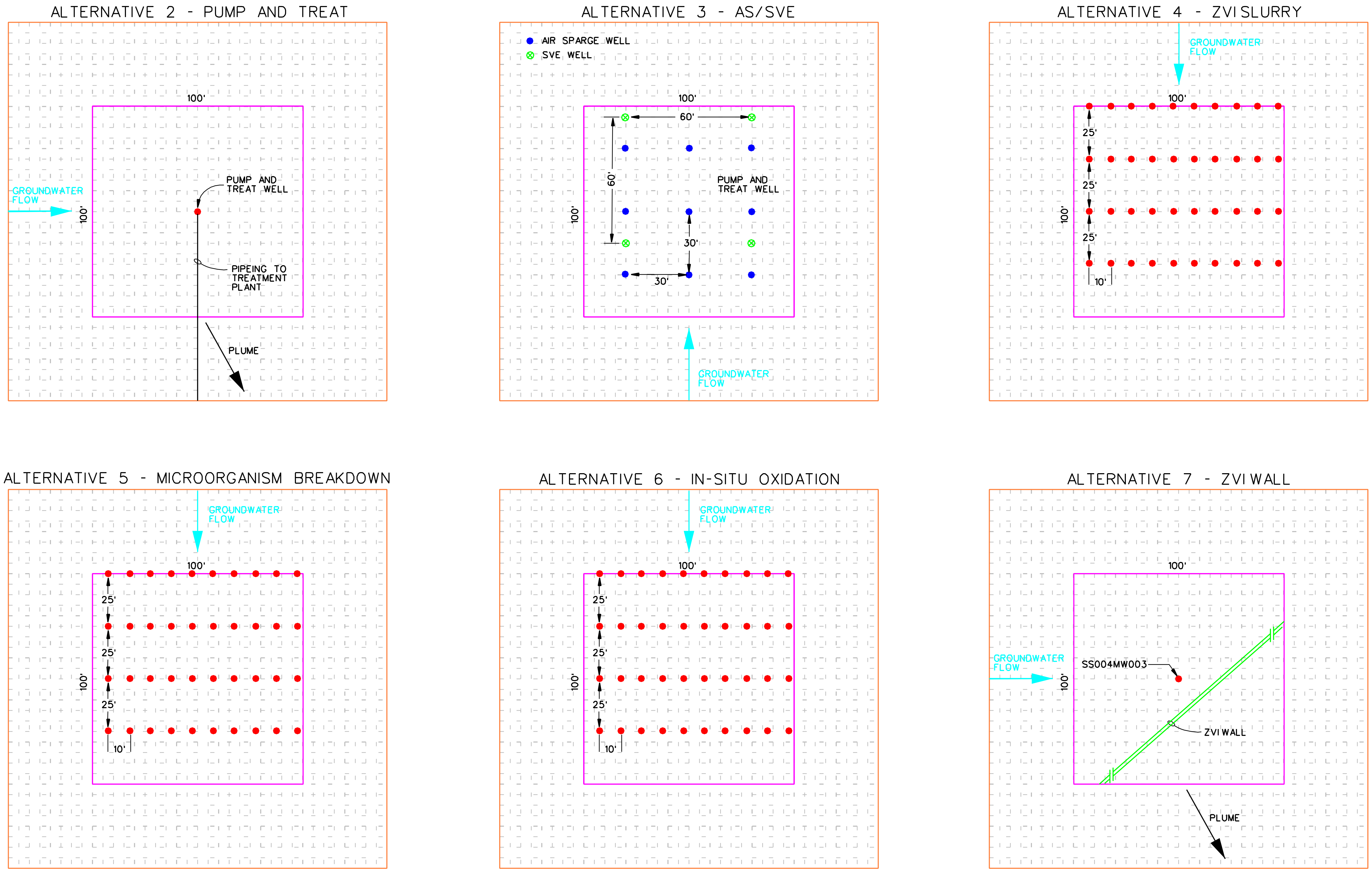
The pump and treat strategy contains and treats contaminated groundwater. It involves pumping groundwater from underground and treating the water above ground. After enough of the groundwater is pumped from the ground, the contaminants begin to be flushed from the aquifer.

Considering the limited areas targeted for additional source control, it has been assumed vertical wells would be effective for pumping groundwater. The water pumped from the ground would be treated in the existing water treatment plant using UVOX. The treated groundwater would be discharged to a sanitary or storm sewer or surface water body.

7.4.3.2 Conceptual Design: Vertical Extraction Well System

It has been assumed two vertical groundwater extraction wells would be required. The wells would be placed at the shallow groundwater system directly above the Navarro Formation (assumed to be 40 feet bgs). The effective screen length for each vertical well would be 20 feet and would consist of slotted stainless steel wire wrapped screen. For this evaluation it has been assumed each vertical well would pump about 10 to 20 gpm for a maximum withdrawal of about 57,600 gpd of groundwater.

Extracted groundwater would travel through a piping network to the existing treatment plant.



NOTE:

SS052 8 TREATMENT AREAS

FIGURE 7.4
MP Area CMA Conceptual Layouts
Zone 4 CMS Report
Kelly AFB, San Antonio, Texas

CH2MHILL

7.4.3.3 Treatment and Disposal

Using CMA 2, extracted groundwater would be treated to the MCL standards using UVOX technology. The treated groundwater would be discharged to the storm sewer system or a surface water body (i.e., drainage channel).

7.4.4 CMA 3: Flow-Through Reactive Wall and Monitored Natural Attenuation

The area targeted for additional source control at the MP site consists of the area outside the slurry wall defined by the 100 ppb PCE contour. For costing purposes, this area has been divided into eight areas 100 feet by 100 feet. This CMA includes using reactive walls strategically placed to optimize treatment of contaminated groundwater (e.g., perpendicular to groundwater flow). For this evaluation, it has been assumed that a total of 400 feet of reactive walls would be placed. **Figure 7.4** provides a conceptual layout of this CMA.

7.4.4.1 General Technology Description

Reactive walls, or treatment walls, are structures installed underground to treat contaminated groundwater.

Treatment walls are put in place by first constructing a trench across the flow path of contaminated groundwater. The trench is then filled with a chosen material based on the types of contaminants found at a site. As the contaminated groundwater flows through the treatment wall, the contaminants are chemically changed into less toxic or nontoxic substances.

For chlorinated solvents, iron filings are the most commonly used treatment material. The iron filings will chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene.

Reactive walls can effectively treat the water that passes through them, but they cannot treat pollutants that are already downstream. These dissolved pollutants, however, eventually will be flushed out by the clean, treated water that has passed through the wall. By placing many parallel walls in a contaminated area, it may be possible to speed up the clean up of the entire area.

7.4.4.2 Conceptual Design: Reactive Wall

Using CMA 3, it has been assumed that treatment would be performed by strategically placing reactive walls in the targeted areas (e.g., at on the downgradient side of the higher concentration areas). To achieve this goal, it has been assumed that reactive walls would be placed for 400 feet.

For this evaluation, it has been assumed that a trench would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs) using conventional earth-working equipment. It has been assumed that the trench would be 400 feet long and two feet wide. The trench would then be backfilled with iron filings from the base of the trench to a depth of two to three feet above the saturated gravel (assumed to be 20 feet bgs) and backfilled with native soils (sand).

7.4.4.3 Treatment and Disposal

Because reactive walls treat the contaminated water underground, there are no aboveground treatment plants or water disposal issues.

7.4.5 CMA 4: Injection of Flow-Through Reactive Wall Slurry and Monitored Natural Attenuation

The area targeted for additional source control at the MP site consists of the area outside the slurry wall defined by the 100 ppb PCE contour. For costing purposes, this area has been divided into eight areas 100 feet by 100 feet. This CMA includes strategically injecting reactive slurry to optimize treatment of contaminated groundwater (e.g., perpendicular to groundwater flow).

For this evaluation, it has been assumed that a total of 400 feet of ZVI reactive slurry would be placed. It has been assumed placement of the slurry would be via a line(s) of injection wells located on 10–foot centers. **Figure 7.4** provides a conceptual layout of this CMA.

7.4.5.1 General Technology Description

Reactive slurry walls, are structures installed underground to treat contaminated groundwater. They are put in place by injecting an iron slurry in a line of injection wells. As the contaminated groundwater flows through the treatment wall, the contaminants are chemically changed into less toxic or nontoxic substances.

For chlorinated solvents, a ZVI slurry is the most commonly used treatment material. The ZVI slurry chemically reduces and strips the chlorines from the solvents, converting them to harmless ethene.

Reactive walls effectively treat the water that passes through them but cannot treat pollutants that are already downstream. However, these dissolved pollutants will eventually be flushed out by the clean, treated water that has passed through the wall. By placing many parallel walls in a contaminated area, it may be possible to speed up the clean up of the entire area.

7.4.5.2 Conceptual Design: Reactive Walls and Slurry Injection

Using CMA 4, it has been assumed that treatment would be performed by strategically injecting reactive slurry into the targeted areas (e.g., at on the downgradient side of the higher concentration areas). To achieve this goal, it has been assumed that reactive slurry walls would be placed for 400 feet.

For this evaluation, it was assumed that a slurry would be injected from the top of the Navarro Clay (assumed to be 40 feet bgs) using injection wells. The wells would be spaced about every 10 feet for 400 feet for a total of 40 wells. Each well would be injected with a ZVI slurry from the top of the Navarro to two or three feet above the water table.

7.4.5.3 Treatment and Disposal

Because reactive walls treat the contaminated water underground, there are no aboveground treatment plants or water disposal issues.

7.4.6 CMA 5: Limited Microorganism Breakdown and Monitored Natural Attenuation

The area targeted for additional source control at the MP site consists of the area outside the slurry wall defined by the 100 ppb PCE contour. For costing purposes, this area has been divided into eight areas 100 feet by 100 feet. This CMA includes enhanced biodegradation applied specifically to these areas. **Figure 7.4** provides a conceptual layout of this CMA.

7.4.6.1 General Technology Description

Enhanced biodegradation is a treatment process for groundwater contamination. Enhanced biodegradation uses naturally occurring microorganisms (bacteria) to degrade, or break down, hazardous substances into less toxic or nontoxic substances. Microorganisms, just like humans, digest organic substances for nutrients and energy.

To speed up the natural breakdown of fuels or solvents, technologies are available that help create favorable environmental conditions for the microorganisms to digest the contaminants. For chlorinated solvents, two types of enhanced biodegradation can be used; aerobic cometabolism and anaerobic reductive dehalogenation. With aerobic cometabolism, other organic compounds (such as methane or propane) are injected into the groundwater along with oxygen to accelerate the biodegradation of the chlorinated solvents. The microorganisms digest and grow using the added organic compounds. They digest the chlorinated solvents when the added organic compounds are gone.

With anaerobic reductive dehalogenation, more complex organic compounds (e.g., vegetable oil or molasses) are added without oxygen. The microorganisms digest the complex organics and use up any remaining oxygen. Under these conditions, the microorganisms may respire ("breathe") the chlorinated solvents, since oxygen is not present. The chlorine atoms are removed from the chlorinated compounds in steps and the eventual result is harmless ethene. However, during the process, byproducts may accumulate from the degradation of TCE; these byproducts include DCE and vinyl chloride. The byproducts themselves will eventually be degraded.

To be effective, both enhanced biodegradation processes require that relatively large amounts of the organic supplements be injected into the ground. Injection wells typically must be placed every 25 feet or less. The organic compounds must be reinjected every six months, and the entire process can take up to two years to complete.

7.4.6.2 Conceptual Design: Enhanced Anaerobic Breakdown

Using CMA 5, vegetable oil would be injected into the shallow groundwater system. To achieve treatment of the eight areas using this method it has been assumed 40 injection wells would be evenly spaced over each of the eight areas to deliver the organic material to microorganisms in the aquifer (320 wells). Injection of the organic material would occur every six months for one year (two injections) to provide enough material to effectively degrade the contaminants.

The wells would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs). Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing.

7.4.6.3 Treatment and Disposal

Because natural biodegradation processes treat water underground, there are no aboveground treatment plants and no water disposal issues.

7.4.7 CMA 6: Limited Oxygen Treatment and Monitored Natural Attenuation

The area targeted for additional source control at the MP site consists of the area outside the slurry wall defined by the 100 ppb PCE contour. For costing purposes, this area has been divided into eight areas 100 feet by 100 feet. This CMA includes oxygen treatment (in situ oxidation) using potassium permanganate applied specifically to these areas. **Figure 7.4** provides a conceptual layout of this CMA.

7.4.7.1 General Technology Description

In situ, or in place, oxidation is a technology that uses chemicals to treat contaminated soils and groundwater. The chemicals are injected into the aquifer via wells, and treatment takes place below the ground surface.

Two common compounds used for in situ oxidation are hydrogen peroxide and potassium permanganate. Both can be used to treat the solvents present in shallow groundwater, however, potassium permanganate has been assumed since it is less hazardous than other oxidizing chemicals. Once the pollutants come into contact with the oxidizing chemicals, they are turned into carbon dioxide, or less toxic or nontoxic substances, through chemical reactions.

To be effective, in situ oxidation requires that relatively large amounts of oxidizing chemicals be injected into the ground. Injection wells typically must be placed every 50 feet or less to quickly clean up an area. If longer times are acceptable, they may be placed further apart. Typically, the chemicals must be reinjected twice for the process to be effective. The oxidation process can typically be completed in less than six months.

7.4.7.2 Conceptual Design: In Situ Oxidation

Groundwater would be treated in the eight areas. To achieve this goal, potassium permanganate would be injected into the shallow groundwater system. To achieve treatment of the eight areas using this method, it has been assumed that 40 injection wells would be evenly spaced over each of the eight areas (320 wells total) to deliver the oxidizing chemical into the aquifer. Injection of the oxidizing chemical would occur every six months for one year (two injections per year) to provide enough material to effectively degrade the contaminants.

The injection wells would be constructed to reach the top of the Navarro Clay (assumed to be 40 feet bgs). Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing.

7.4.7.3 Treatment and Disposal

Because this technology treats contaminated water underground, there are no aboveground treatment units or water discharge issues. As stated above, there are aboveground storage and mixing tanks located in secured buildings.

7.4.8 CMA 7: Air Injection/Vapor Removal and Monitored Natural Attenuation

The area targeted for additional source control at the MP site consists of the area outside the slurry wall defined by the 100 ppb PCE contour. For costing purposes, this area has been divided into eight areas 100 feet by 100 feet. This CMA includes air injection and vapor removal applied specifically to these areas. **Figure 7.4** provides a conceptual layout of this CMA.

7.4.8.1 General Technology Description

Air injection (AS) with vapor removal is a simple process that physically separates contaminants from groundwater by turning them into vapors or gases and then collecting them. AS means pumping air into the ground below the water table. The air then rises up through the groundwater and pulls the pollutants out of the water. The vapors and gases are collected by applying a vacuum through a system of underground wells above the water table (this is called SVE).

AS/SVE systems are used for contaminants that have a tendency to evaporate easily. The contaminants found in shallow groundwater are VOCs and evaporate easily.

AS is accomplished through a series of injection wells that are drilled to below the water table. These wells are placed 15 to 50 feet apart. Air piping must run from an air compressor to each injection well. The SVE wells are similar although they are not drilled to below the water table. Soil vapors are purged from the SVE wells and treated at a treatment plant located on the ground surface. Treatment plants may treat the vapors using carbon adsorption, or burning (incineration or catalytic oxidation). The treatment plant and air compressors will be located throughout the area to be treated.

7.4.8.2 Conceptual Design: Air Sparging/Soil Vapor Extraction

Using CMA 7, an AS/SVE system consisting of both air injection wells and SVE wells would be included at each of the eight areas. Nine air injection wells and four SVE vacuum wells were assumed required at each area. Wells would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs). Each well would be constructed of 10 feet of SS screen and 20 feet of SS casing.

Piping would connect the AS wells to air compressors located on the surface. Air would travel underground through this piping where it would bubble up through the shallow groundwater and volatilize contaminants before being captured by the SVE wells. There would also be piping connecting the SVE wells to an air treatment plant. Granulated activated carbon would be used to clean the contaminants from the extracted air. It has been assumed that one aboveground treatment plant would be needed.

7.4.8.3 Treatment and Disposal

With AS/SVE systems, the groundwater is treated in situ by the air volatilizing the contaminants, but the air must then be treated before discharge. This is accomplished by flowing the air through granulated activated carbon, which traps the contaminants. The clean air can then be discharged directly. Spent activated carbon canisters must be disposed of properly.

7.5 SS051 (Source Control) CMAs

Monitored Natural Attenuation (MNA) was considered a common element of all CMAs, since it is an ongoing, naturally occurring process. Additionally, the currently operating Zone 4 source control remedial systems are a common element of all CMAs.

7.5.1 No Action Baseline

The No Action Baseline consists of evaluating the plume with no CMA alternatives. The No Action Baseline is not considered as a CMA, but a tool to compare the effectiveness of each CMA against. The existing remedial systems are removed in the model, and the plume is modeled with no current or future CMA in operation to estimate the cleanup time. The estimated cleanup time with No Action is over 100 years.

7.5.2 CMA 1: Existing Source Control Systems and Monitored Natural Attenuation

This CMA includes using the existing source control systems and MNA throughout the area. The current source control system at East Kelly consists of horizontal and vertical extraction wells along the entire southern and eastern boundaries, and in-situ bio enhancement and chemical oxidation at the source area and other areas of higher concentrations. The bio enhancement consists of injecting vegetable oil into the shallow aquifer, and sodium permanganate for the chemical oxidation .**Figure 7.5** provides a conceptual layout of this CMA. The SS051 source area consists of four small areas located around four monitoring wells with higher concentrations of COCs.

7.5.2.1 General Technology Description

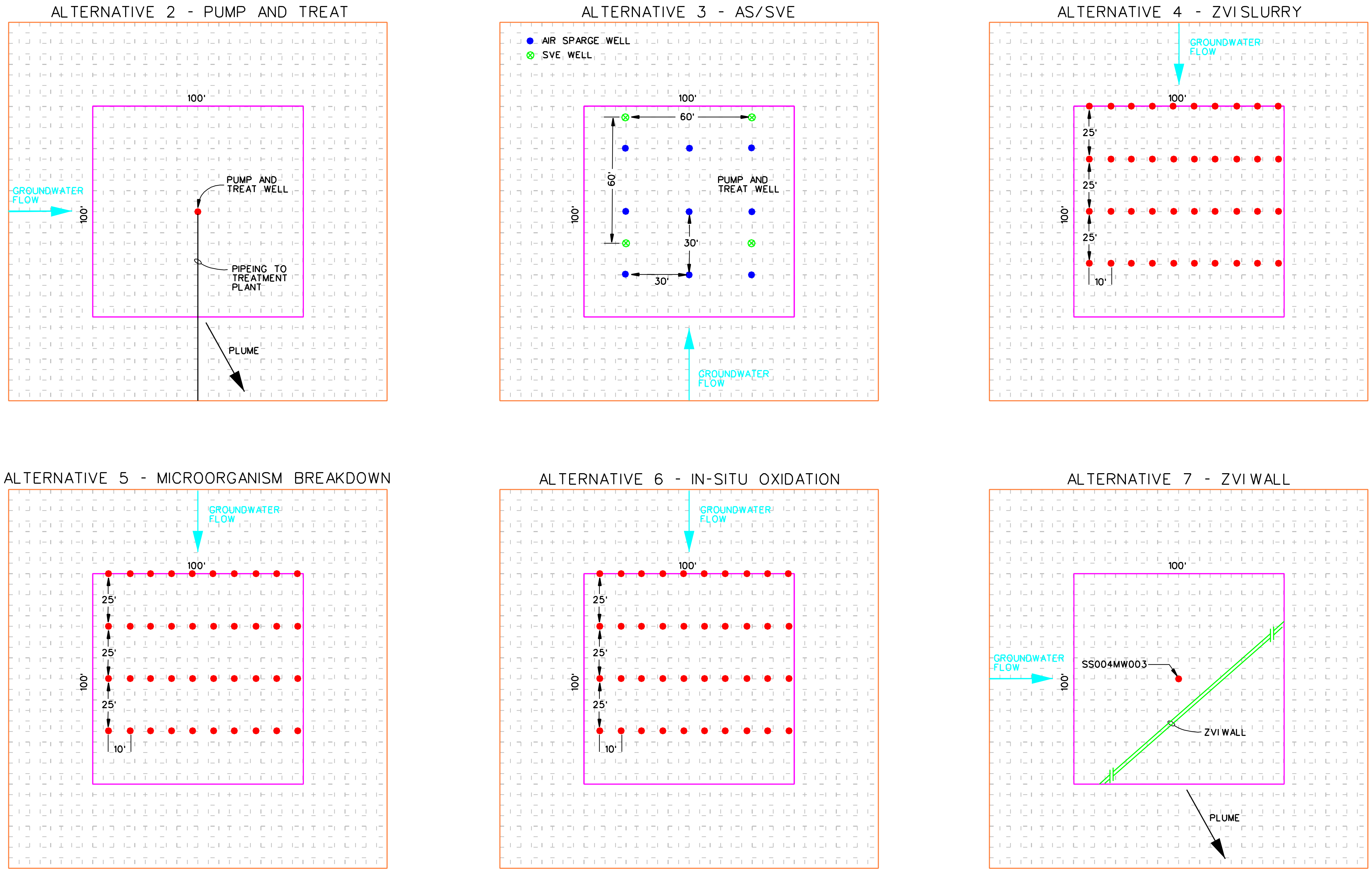
The current source control systems at the MP Site consist of a slurry wall surrounding the entire MP Site source area and extraction wells along the base perimeter between the MP Site source area and off base. The current source control system at Zone 4 consists of horizontal and vertical extraction wells along its entire southern and eastern boundaries.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The NCP, the regulatory framework for the Superfund program, defines natural attenuation as a process that “will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem.”

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption



NOTE:

SS051 4 TREATMENT AREAS

FIGURE 7.5
SS051 Areas CMA Conceptual Layouts
Zone 4 Technical Evaluation CMAs
Kelly AFB, San Antonio, Texas

CH2MHILL

- Volatilization

7.5.2.2 Conceptual Design

The design and construction for the existing source treatment was completed in July 2000. In addition to these measures, this CMA would include MNA.

It has been assumed that 16 new monitoring wells would be installed (four at each area) and sampled annually for VOCs and natural attenuation indicator parameters. It has been assumed the new monitoring wells would be constructed of 20 feet of SS casing and 10 feet of SS screen. A minimal amount of time would be required for designing and installing the additional monitoring wells since all other systems are already operational. Once implemented, operating and maintaining the systems would cause few traffic disruptions on-base. Little noise level or other disruptions are expected during operation and maintenance.

7.5.2.3 Treatment and Disposal

Using CMA 1, extracted groundwater is currently being treated to the MCL standards using UVOX technology. The treated groundwater is being discharged to Leon Creek.

Because MNA treats the contaminated water underground, there are no aboveground treatment plants, other than existing plants, and no water disposal issues.

7.5.3 CMA 2: Existing Source Control with Pump and Treat and Monitored Natural Attenuation

The SS051 source area consists of four small areas located around 4 monitoring wells with higher concentrations of COCs. This CMA includes one vertical extraction well at each of the four higher concentration areas. **Figure 7.5** provides a conceptual layout of this CMA.

7.5.3.1 General Technology Description

The pump and treat strategy contains and treats contaminated groundwater. It involves pumping groundwater from underground and treating the water above ground. After enough of the groundwater is pumped out of the ground, the contaminants begin to be flushed from the aquifer.

Considering the limited areas targeted for additional source control, it has been assumed that vertical wells would be effective for pumping groundwater. The water pumped from the ground would be treated in a newly constructed water treatment plant using an ultraviolet oxidation system. The treated water would be discharged to a sanitary or storm sewer, or surface water body.

7.5.3.2 Conceptual Design: Vertical Extraction Well System

It has been assumed that four vertical groundwater extraction wells would be required. The wells would be placed at the shallow groundwater system directly above the Navarro Formation (assumed to be 40 feet bgs). The effective screen length for each vertical well would be 20 feet and would consist of slotted stainless steel wire wrapped screen. For this evaluation, each vertical well would pump about 10 to 20 gpm for a maximum withdrawal of about 115,200 gallons per day (gpd) of groundwater.

It has been assumed that extracted groundwater would travel through a piping network to a newly constructed treatment plant centrally located to the four areas.

7.5.3.3 Treatment and Disposal

Using this CMA, extracted groundwater would be treated to the MCL standards using UVOX technology. The treated groundwater would be discharged to the storm sewer system or a surface water body (i.e., drainage channel).

7.5.4 CMA 3: Flow-Through Reactive Walls and Monitored Natural Attenuation

The SS051 source area consists of four small areas located around 4 monitoring wells with higher concentrations of COCs. This CMA includes using reactive walls applied at the downgradient side of each of the four areas. **Figure 7.5** provides a conceptual layout of this CMA.

7.5.4.1 General Technology Description

Reactive walls, or treatment walls, are structures installed underground to treat contaminated groundwater.

Treatment walls are put in place by first constructing a trench across the flow path of contaminated groundwater. The trench is then filled with a chosen material based on the types of contaminants found at a site. As the contaminated groundwater flows through the treatment wall, the contaminants are chemically changed into less toxic or nontoxic substances.

For chlorinated solvents, iron filings are the most commonly used treatment material. The iron filings will chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene.

Reactive walls can effectively treat the water that passes through them, but they cannot treat pollutants that are already downstream. These dissolved pollutants, however, eventually will be flushed out by the clean, treated water that has passed through the wall. By placing many parallel walls in a contaminated area, it may be possible to speed up the clean up of the entire area.

7.5.4.2 Conceptual Design: Reactive Walls

Using this CMA, treatment would be performed at each of the four higher concentration areas. To achieve this goal, it has been assumed that each reactive wall would need to be 200 feet in length (800 feet total).

For this evaluation, it has been assumed that a trench would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs) using conventional earth-working equipment. It has been assumed that each trench would be 200 feet long and 2 feet wide. The trenches would then be backfilled with iron filings from the base of the trench to a depth of two to three feet above the saturated gravel (assumed to be 20 feet bgs) and backfilled with native soils (sand).

7.5.4.3 Treatment and Disposal

Because reactive walls treat the contaminated water underground, there are no aboveground treatment plants or water disposal issues.

7.5.5 CMA 4: Injection of Flow-Through Reactive Wall Slurry and Monitored Natural Attenuation

The SS051 source area consists of four small areas located around four monitoring wells with higher concentrations of COCs. This CMA includes using four flow-through reactive slurry lines on the downgradient side of each area. A Zero Valent Iron (ZVI) slurry would be injected into a line of injection wells located on 10-foot centers. **Figure 7.5** provides a conceptual layout of this CMA.

7.5.5.1 General Technology Description

Flow-through reactive walls are structures installed underground to treat contaminated groundwater. They are put in place by injecting an iron slurry in a line of injection wells. As the contaminated groundwater flows through the treatment wall, the contaminants are chemically changed into less toxic or nontoxic substances.

For chlorinated solvents, a ZVI slurry is the most commonly used treatment material. The ZVI slurry chemically reduces and strips the chlorines from the solvents, converting them to harmless ethene.

Reactive walls effectively treat the water that passes through them but cannot treat pollutants that are already downstream. However, the clean, treated water that has passed through the wall will eventually flush out these dissolved pollutants. By placing many parallel walls in a contaminated area, it may be possible to hasten the entire area’s cleanup.

7.5.5.2 Conceptual Design: Reactive Walls and Slurry Injection

For this evaluation, it has been assumed that four ZVI slurries would be installed. It was assumed that a ZVI slurry would be injected from the top of the Navarro Clay (assumed to be 40 feet bgs) using injection wells. The wells would be spaced about every 10 feet for 200 feet in each area, for a total of 80 wells in the four areas. Each well would be injected with a ZVI slurry from the top of the Navarro to two or three feet above the water table.

Each well would be constructed of 10 feet of SS screen and 20 feet of SS casing. Each well would be constructed with 20 feet of screen and 20 feet of casing.

7.5.5.3 Treatment and Disposal

Because reactive walls treat contaminated water underground, there are no aboveground treatment plants or water disposal issues.

7.5.6 CMA 5: Limited Microorganism Breakdown and Monitored Natural Attenuation

The SS051 source area consists of four small areas located around four monitoring wells with higher concentrations of COCs. This CMA includes enhanced biodegradation applied specifically to the four areas. **Figure 7.5** provides a conceptual layout of this CMA.

7.5.6.1 General Technology Description

Enhanced biodegradation is a treatment process for groundwater contamination. Enhanced biodegradation uses naturally occurring microorganisms (bacteria) to degrade, or break down, hazardous substances into less toxic or nontoxic substances. Microorganisms, just like humans, digest organic substances for nutrients and energy.

To speed up the natural breakdown of fuels or solvents, technologies are available that help create favorable environmental conditions for the microorganisms to digest the contaminants. For chlorinated solvents, two types of enhanced biodegradation can be used; aerobic cometabolism and anaerobic reductive dehalogenation. With aerobic cometabolism, other organic compounds (such as methane or propane) are injected into the groundwater along with oxygen to accelerate the biodegradation of the chlorinated solvents. The microorganisms digest and grow using the added organic compounds. They digest the chlorinated solvents when the added organic compounds are gone.

With anaerobic reductive dehalogenation, more complex organic compounds (e.g., vegetable oil or molasses) are added without oxygen. The microorganisms digest the complex organics and use up any remaining oxygen. Under these conditions, the microorganisms may respire (“breathe”) the chlorinated solvents, since oxygen is not present. The chlorine atoms are removed from the chlorinated compounds in steps and the eventual result is harmless ethene. However, during the process, byproducts may accumulate from the degradation of TCE; these byproducts include DCE and vinyl chloride. The byproducts themselves will eventually be degraded.

To be effective, both enhanced biodegradation processes require that relatively large amounts of the organic supplements be injected into the ground. Injection wells typically must be placed every 25 feet or less. The organic compounds must be re-injected every six months, and the entire process can take up to two years to complete.

7.5.6.2 Conceptual Design: Enhanced Anaerobic Breakdown

Using CMA 5, vegetable oil would be injected into the shallow groundwater system. To achieve treatment of the four areas using this method, it has been assumed that 40 injection wells would be evenly spaced over each of the four areas (160 wells total) to deliver the organic material to microorganisms in the aquifer. Injection of the organic material would occur every six months for one year (two injections per year) to provide enough material to effectively degrade the contaminants.

The wells would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs). Each well would be constructed of 10 feet of SS screen and 20 feet of SS casing.

7.5.6.3 Treatment and Disposal

Because natural biodegradation processes treat contaminated water underground, there are no aboveground treatment plants and no water disposal issues.

7.5.7 CMA 6: Limited Oxygen Treatment and Monitored Natural Attenuation

The SS051 source area consists of four small areas located around 4 monitoring wells with higher concentrations of COCs. This CMA includes oxygen treatment (in situ oxidation) using potassium permanganate applied specifically to the four areas of higher concentrations. **Figure 7.5** provides a conceptual layout of this CMA.

7.5.7.1 General Technology Description

In situ, or in place, oxidation is a technology that uses chemicals to treat contaminated soils and groundwater. The chemicals are injected into the aquifer via wells, and treatment takes place underground.

Two common compounds used for in situ oxidation are hydrogen peroxide and potassium permanganate. Both can be used to treat the solvents present in shallow groundwater, however, potassium permanganate has been assumed to be the choice since it is less hazardous than other oxidizing chemicals. Once the pollutants come into contact with the oxidizing chemicals, they are turned into carbon dioxide, or less toxic or nontoxic substances, through chemical reactions.

To be effective, in situ oxidation requires that relatively large amounts of oxidizing chemicals be injected into the ground. Injection wells typically must be placed every 50 feet or less to quickly clean up an area. If longer times are acceptable, they may be placed further apart. Typically, the chemicals must be reinjected twice for the process to be effective. The oxidation process can typically be completed in less than six months.

7.5.7.2 Conceptual Design: In situ Oxidation

Groundwater would be treated in the four areas of higher concentrations. To achieve this goal, potassium permanganate would be injected into the shallow groundwater system. To achieve treatment of the four areas using this method, it has been assumed that 40 injection wells would be evenly spaced over each of the four areas (160 wells total) to deliver the oxidizing chemical into the aquifer. Injection of the oxidizing chemical would occur every six months for one year (two injections per year) to provide enough material to effectively degrade the contaminants.

The wells would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs). Each well would be constructed with 10 feet of SS screen and 20 feet of SS casing.

7.5.7.3 Treatment and Disposal

Because this CMA treats contaminated groundwater underground, there are no aboveground treatment plants or water disposal issues. As stated above, there are aboveground storage and mixing tanks located in secured buildings.

7.5.8 CMA 7: Air Injection/Vapor Removal and Monitored Natural Attenuation

The SS051 source area consists of four small areas located around 4 monitoring wells with higher concentrations of COCs. This CMA includes air injection and vapor removal applied specifically to those areas. **Figure 7.5** provides a conceptual layout of this CMA.

7.5.8.1 General Technology Description

Air injection (AS) with vapor removal is a simple process that physically separates contaminants from groundwater by turning them into vapors or gases and then collecting them. AS means pumping air into the ground below the water table. The air then rises up through the groundwater and pulls the pollutants out of the water. The vapors and gases are collected by applying a vacuum through a system of underground wells above the water table (this is called SVE).

AS/SVE systems are used for contaminants that have a tendency to evaporate easily. The contaminants found in shallow groundwater are VOCs and evaporate easily.

AS is accomplished through a series of injection wells that are drilled to below the water table. Typically, these wells are placed 15 to 50 feet apart. Air piping must run from an air compressor to each injection well. The SVE wells are similar although they are not drilled to below the water table. Soil vapors are purged from the SVE wells and treated at a treatment plant located on the ground surface. Treatment plants may treat the vapors using carbon adsorption, or burning (incineration or catalytic oxidation). The treatment plant and air compressors will be located throughout the area to be treated.

7.5.8.2 Conceptual Design: Air Sparging/Soil Vapor Extraction

Using this CMA, an AS/SVE system consisting of both air injection wells and SVE wells would be included at each of the four areas. At each area it is assumed that nine air injection wells and four SVE vacuum wells are required. Wells would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs). Each well would be constructed of 10 feet of SS screen and 20 feet of SS casing.

Piping would connect the AS wells to air compressors located on the surface. Air would travel underground through this piping where it would bubble up through the shallow groundwater and volatilize contaminants before being captured by the SVE wells. Piping would connect the SVE wells to air treatment plants. Granulated activated carbon would be used to clean the contaminants from the extracted air. It has been assumed that two aboveground treatment plants would be needed, one for the two northern areas and one for the two southern areas).

7.5.8.3 Treatment and Disposal

With AS/SVE systems, the groundwater is treated in situ by the air volatilizing the contaminants, but the air must then be treated before discharge. This is accomplished by flowing the air through granulated activated carbon, which traps the contaminants. The clean air can then be discharged directly. Spent activated carbon canisters must be disposed of properly.

7.6 Off-Base Corrective Measures Alternatives

MNA was considered a common element of all CMAs, since it is an ongoing, naturally occurring process. Additionally, the currently operating MP and Zone 4 source control remedial systems are a common element of all CMAs.

7.6.1 No Action Baseline

The No Action Baseline consists of evaluating the plume with no CMA alternatives. The No Action Baseline is not considered as a CMA, but a tool to compare the effectiveness of each CMA against. The existing remedial systems are removed in the model, and the plume is modeled with no current or future CMA in operation to estimate the cleanup time. The estimated cleanup time with No Action is over 100 years.

7.6.2 CMA A: Pump and Treat Plumewide, a River Trench, and Monitored Natural Attenuation

This CMA includes a plumewide pump and treat system with a groundwater extraction trench placed along the bank of the San Antonio River. **Figure 7.6** provides a conceptual layout of this CMA. The water pumped from the ground is treated through a water treatment system, such as air strippers, carbon filters, or an UVOX system. The treated water can then be discharged to a sanitary or storm sewer or surface water body. It may also be reinjected into the ground. Reinjection may speed the flushing of the contaminants from the ground, but it may be difficult to operate due to plugging of the reinjection wells. Furthermore reinjecting treated groundwater requires double the level of effort without doubling the effectiveness.

7.6.2.1 General Technology Descriptions

The pump and treat strategy contains and treats contaminated groundwater. It involves pumping groundwater from the subsurface and treating the water above ground. After enough of the groundwater is pumped out of the ground, the contaminants begin to be flushed from the aquifer. Groundwater can be pumped from vertical wells, from horizontally drilled wells, or from trenches. The well spacing depends on geologic and hydrogeologic conditions in the aquifer, the availability of land, reasonable achievable timeframes.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that “will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem.”

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

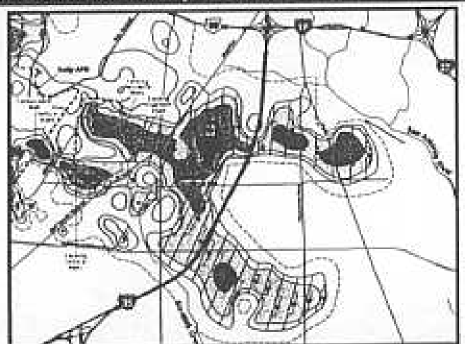
- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.2.2 Conceptual Design: Horizontal Extraction Well Systems

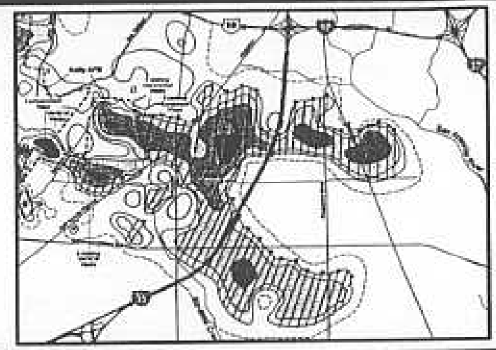
Based on the technology evaluation presented in Section 4.0, vertical wells were considered ineffective for the extensive off-site plume areas. Therefore, horizontal wells are included in

Corrective Measures Alternatives Conceptual Layouts

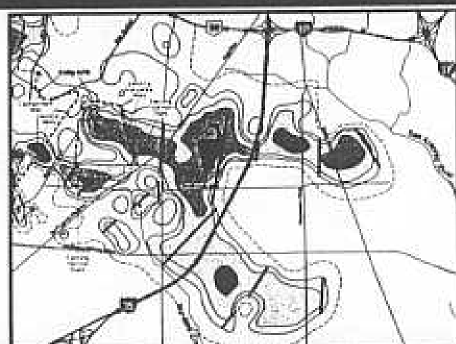
Potential CMA A: Zone 4
Pump and Treat with Horizontal Wells Plumewide with Groundwater Interception Trench at River and MNA



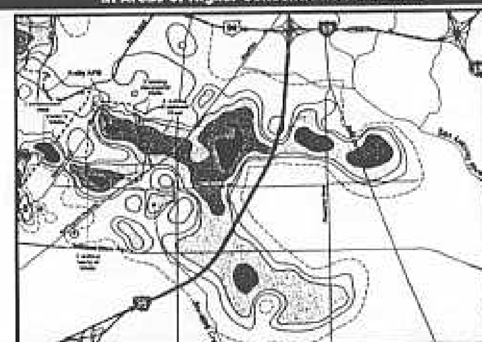
Potential CMA C: Zone 4
Pump and Treat Plumewide with Reinjection and MNA



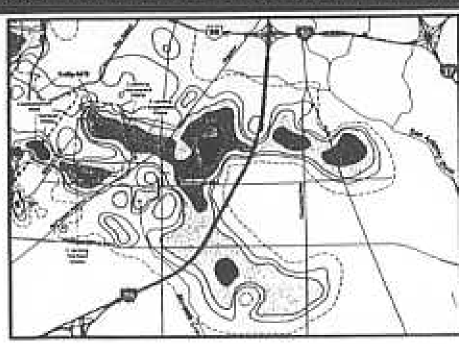
Potential CMA E: Zone 4
Flow-Through Reactive Walls Plumewide and MNA



Potential CMA G: Zone 4
Microorganism Breakdown at Areas of Higher Concentration and MNA



Potential CMA H: Zone 4
Oxygen Treatment at Areas of Higher Concentration and MNA



Potential CMA I: Zone 4
Air Injection/Vapor Removal at Areas of Higher Concentration and MNA

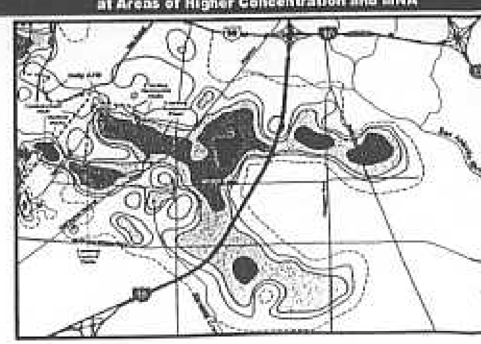


Figure 7.6
CMA Conceptual Layouts
Zone 4 CMS Report
Kelly Air Force Base, Texas

this CMA. Plumewide groundwater extraction would be performed using 180 horizontal wells spaced every 1,000 feet.

The horizontal wells would be placed at the base of the shallow groundwater system directly above the Navarro Formation. For this evaluation, this depth was presumed to be 40 feet bgs. The effective screen length for each horizontal well would be 1,000 feet and would consist of slotted high-density polyethylene (HDPE) pipe. Local geology and irregularities in the Navarro Group topography may require installing horizontal wells in multiple smaller sections. The actual location of horizontal wells would be based upon a detailed analysis of the local hydrogeology.

For this evaluation, each horizontal well would pump about 60 to 80 gpm for a maximum withdrawal of about 21 mgd of groundwater. The trench was assumed to produce 400 gpm, for a total of about 0.6 mgd of groundwater.

The trench along the bank of the San Antonio River would be 2,000 feet long, 25 feet deep, with a slotted HDPE pipe placed along the base of the trench. The trench would be backfilled with 15 feet of gravel and covered with native soils.

Extracted groundwater would travel through an extensive piping network to a presumed total of 45 aboveground treatment plants, each plant capable of treating the discharge from approximately four wells (about 0.5 mgd). The treatment plants generally would be located on nonresidential lots when possible; it is assumed these lots will have to be purchased.

Whenever possible, the wells and piping would be installed under roads to minimize disruption to private land and daily traffic due to road closures during construction and operation.

Actual system design would take up to two years to complete. Once designed, the systems could take up to four years to construct. During construction, low levels of dust and construction waste are expected, with a moderate-to-high level of construction noise. A high level of traffic disruption would occur. Once implemented, operating and maintaining the systems would cause little traffic disruption and a moderate-to-high level of noise and maintenance disruptions (e.g., access to properties).

7.6.2.3 Treatment and Disposal

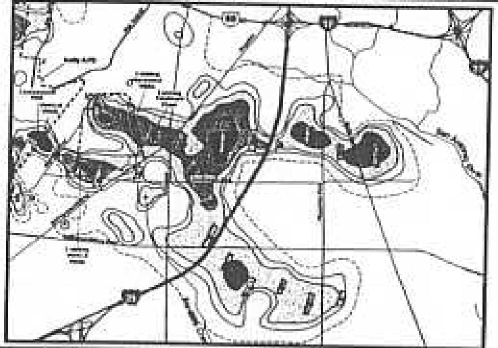
Under this CMA, extracted groundwater would be treated to the MCL standards using UVOX technology. The treated groundwater would be discharged to the storm sewer system or a surface water body (i.e., drainage channel).

7.6.3 CMA A1: Pump and treat Plumewide Down the Centerline of the Plume, a River Trench, and Monitored Natural Attenuation

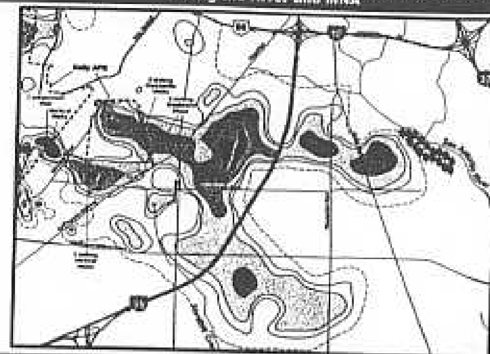
This CMA includes a plumewide pump and treat system with a groundwater extraction trench placed along the bank of the San Antonio River. Horizontal extraction wells would be placed down the centerline of the plume every 2,400 feet in the gravel-filled Navarro Troughs. The centerline of the plume is the thickest area of gravel that has filled Navarro Troughs; this is where the greatest amount of groundwater can be extracted. Contaminant concentrations are highest and move the quickest through these gravel troughs. **Figure 7.7** provides a conceptual layout of this CMA.

Corrective Measures Alternative Conceptual Layouts

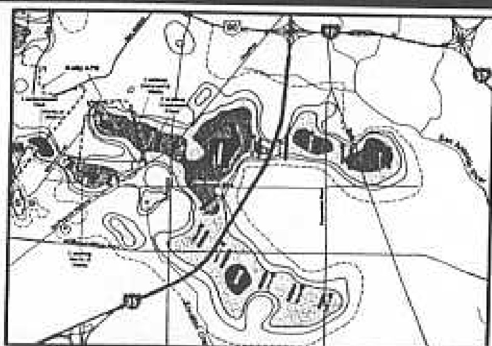
Potential CMA A1: Zone 4
Pump and Treat with Horizontal Wells Down Centerline of Plume Lobes with Groundwater Interception Trench at River and MNA



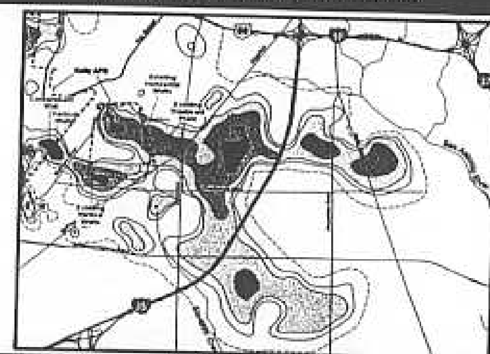
Potential CMA B: Zone 4
Pump and Treat at Areas of Higher Concentration with Phytoremediation along the River and MNA



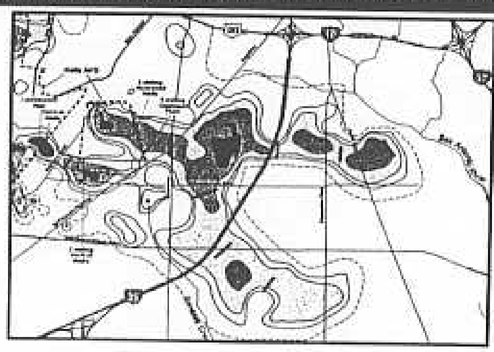
Potential CMA C1: Zone 4
Pump and Treat Down Centerline of Plume Lobes with Reinjection and MNA



Potential CMA D: Zone 4
Existing Source Control Systems and MNA



Potential CMA Set E1: Zone 4
Flow-Through Reactive Walls Down Centerline of Plume Lobes and MNA



Potential CMA F: Zone 4
Flow-Through Reactive Walls at Areas of Higher Concentration and MNA

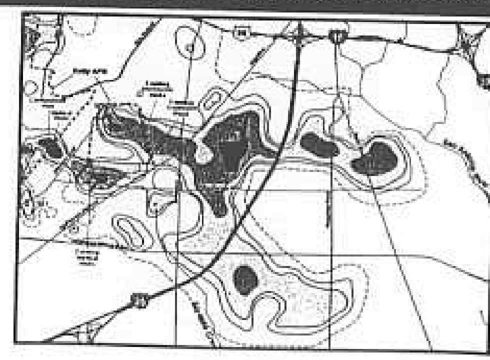


Figure 7.7
CMA Conceptual Layouts
Zone 4 CMS Report
Kelly Air Force Base, Texas

7.6.3.1 General Technology Descriptions

The pump and treat strategy contains and treats contaminated groundwater. It involves pumping groundwater from the subsurface and treating it above ground. After enough of the groundwater is pumped out of the ground, the contaminants begin to be flushed from the aquifer. Groundwater can be pumped from vertical wells, from horizontally drilled wells, or from trenches. The well spacing depends on geologic and hydrogeologic conditions in the aquifer, the availability of land, reasonable achievable timeframes. MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.3.2 Conceptual Design: Horizontal Extraction Well Systems

The pump and treat strategy contains and treats contaminated groundwater. It involves pumping groundwater from the subsurface and treating the water above ground. After enough of the groundwater is pumped out of the ground, the contaminants begin to be flushed from the aquifer. Groundwater can be pumped from vertical wells, from horizontally drilled wells, or from trenches. The well spacing depends on geologic and hydrogeologic conditions in the aquifer, the availability of land, reasonable achievable timeframes.

The water pumped from the ground is treated through a water treatment system, such as air strippers, carbon filters, or an UVOX system. The treated water can then be discharged to a sanitary or storm sewer or surface water body. It may also be reinjected into the ground. Reinjection may speed the flushing of the contaminants from the ground, but it may be difficult to operate due to plugging of the reinjection wells. Furthermore reinjecting treated groundwater requires double the level of effort without doubling the effectiveness.

Nineteen horizontal wells would be spaced every 2,400 feet in the gravel-filled Navarro Troughs that exist down the centerline of the plume.

The horizontal wells, with effective screen lengths of 1,000 feet of slotted HDPE pipe, would be placed at the base of the shallow groundwater system directly above the Navarro Formation. Local geology and irregularities in the Navarro Group topography may require installing horizontal wells in multiple smaller sections. The depth was presumed to be 40 feet bgs. The spacing and location of horizontal wells would be based upon detailed analysis of the local hydrogeology.

For this evaluation, each horizontal well would pump about 60 to 80 gpm for a maximum withdrawal of about 2.2 mgd of groundwater. The trench is assumed to produce 400 gpm for a total of about 0.6 mgd of groundwater.

The trench along the bank of the San Antonio River would be 2,000 feet long, 25 feet deep, with a slotted HDPE pipe placed along the base of the trench. The trench would be backfilled with 15 feet of gravel and covered with native soils.

Extracted groundwater would travel through an extensive piping network to aboveground treatment plants. Five aboveground treatment plants would be required, each plant capable of treating the discharge from approximately four wells (about 0.5 mgd). For this evaluation, it was presumed the treatment plants would be located on nonresidential lots whenever possible. It has been assumed the lots for the treatment plants will have to be purchased.

The wells and piping would be installed under roadways to minimize disruption to private land and daily traffic due to road closures during construction and operation.

The actual design of the systems described for this CMA would take up to two years to complete. Once designed, the systems would take up to four years to construct. During construction, low levels of dust and construction waste can be expected, with a moderate-to-high level of construction noise, and a high level of traffic disruption.

Once implemented, operating, and maintaining the systems would cause little traffic disruption and moderate-to-high levels of noise and maintenance disruptions (e.g., access to properties).

7.6.3.3 Treatment and Disposal

Under this CMA, extracted groundwater would be treated to the MCL standards using UVOX technology. The treated groundwater would be discharged to the storm sewer system or a surface water body (i.e., drainage channel).

7.6.4 CMA B: Limited Pump and Treat, Phytoremediation, and Monitored Natural Attenuation

This CMA includes using pump and treat technology applied specifically to areas of the plume with TCE concentrations in the groundwater at or above 100 ppb. Phytoremediation along the San Antonio River would be included as part of this CMA. **Figure 7.6** provides a conceptual layout of this CMA.

7.6.4.1 General Technology Description

The pump and treat strategy contains and treats contaminated groundwater. It involves pumping groundwater from the subsurface and treating the water above ground. After enough of the groundwater is pumped out of the ground, the contaminants begin to be flushed from the aquifer. Groundwater can be pumped from vertical wells, from horizontally drilled wells, or from trenches. The well spacing depends on geologic and

hydrogeologic conditions in the aquifer, the availability of land, reasonable achievable timeframes.

The water pumped from the ground is treated through a water treatment system, such as air strippers, carbon filters, or an UVOX system. The treated water can then be discharged to a sanitary or storm sewer or surface water body. It may also be reinjected into the ground. Reinjection may speed the flushing of the contaminants from the ground, but it may be difficult to operate due to plugging of the reinjection wells. Furthermore reinjecting treated groundwater requires double the level of effort without doubling the effectiveness.

Phytoremediation uses living plants to clean up or remediate sites by removing pollutants from the soil and water. Plants help remove and possibly break down some pollutants, including the solvents found in Zone 4 shallow groundwater. Phytoremediation seems to be a promising CMA to help prevent pollutants from spreading into the San Antonio River. It will be used along the banks of the river, where groundwater discharges into it.

Trees are the type of plant most often used for groundwater contamination. As tree roots grow, they reach down near the water table and withdraw contaminated groundwater. Once in the tree, the pollutants may be degraded or released into the atmosphere. Typically, phytoremediation is most effective at cleaning up sites with shallow groundwater since roots have a limited penetration depth and low-to-moderate levels of decontamination. Phytoremediation also can be a visually pleasing approach for cleanup.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.4.2 Conceptual Design: Horizontal Extraction Wells

Using CMA B, groundwater extraction would be performed at sites where TCE was found at levels at or above 100 ppb. To achieve this, horizontal wells would be placed evenly over these areas of the plume. Six horizontal wells would be needed.

Well screens would be placed at the base of the shallow groundwater system directly above the Navarro Formation (assumed to be 40 feet bgs). Each horizontal well would contain a well screen with an effective screen length totaling 1,000 feet of slotted HDPE. Each well would pump about 60 to 80 gpm for a maximum withdrawal of about 0.7 mgd of groundwater. Local geology and irregularities in the Navarro Group topography may require installing horizontal wells in multiple smaller sections.

Extracted groundwater would travel through an extensive piping network to aboveground treatment plants. This CMA includes two aboveground treatment plants with each treatment plant capable of treating the discharge from approximately four wells (about 0.5 mgd). It has been assumed that these lots for the treatment plants would have to be purchased.

In addition to the horizontal extraction wells, this CMA includes planting hybrid poplar trees along a 2,000-foot reach of the San Antonio River. These trees are intended to capture groundwater contamination before it reaches the river. The trees would be spaced 25 feet apart in four rows, for a total of 800 trees.

The wells and piping would be installed under roadways to minimize disruption to private land and daily traffic due to road closures during construction and operation.

The actual design of the systems described for this CMA would take up to one year to complete. Once designed, the systems would take up to two years to construct. During construction, low levels of dust and construction waste can be expected, with moderate-to-high levels of construction noise and traffic disruption.

Once implemented, operating and maintaining the systems would cause little traffic disruption and moderate levels of noise and maintenance disruptions (e.g., access to properties).

7.6.4.3 Treatment and Disposal

Using this CMA, extracted groundwater would be treated to MCL standards using UVOX technology. The treated groundwater is assumed to discharge to the storm sewer system or a surface water body (i.e., drainage channel).

7.6.5 CMA C: Pump and Treat Plumewide, Reinjection of Treated Groundwater, and Monitored Natural Attenuation

This CMA includes plumewide pump and treat and reinjection of the treated groundwater. **Figure 7.6** provides a conceptual layout of this CMA.

Reinjection of treated groundwater was included as an option for disposing water and restoration. For this evaluation, reinjection was assumed to be easier. In actuality, reinjection of treated groundwater may be more difficult due to variations in the local hydrogeology.

7.6.5.1 General Technology Description

The pump and treat strategy contains and treats contaminated groundwater. It involves pumping groundwater from the subsurface and treating the water above ground. After enough of the groundwater is pumped out of the ground, the contaminants begin to be flushed from the aquifer. Groundwater can be pumped from vertical wells, from horizontally drilled wells, or from trenches. The well spacing depends on geologic and

hydrogeologic conditions in the aquifer, the availability of land, reasonable achievable timeframes.

The water pumped from the ground is treated through a water treatment system, such as air strippers, carbon filters, or an UVOX system. The treated water can then be discharged to a sanitary or storm sewer or surface water body. It may also be reinjected into the ground. Reinjection may speed the flushing of the contaminants from the ground, but it may be difficult to operate due to plugging of the reinjection wells. Furthermore reinjecting treated groundwater requires double the level of effort without doubling the effectiveness.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.5.2 Conceptual Design: Horizontal Extraction Well Systems

Using CMA C, plumewide groundwater would be extracted using horizontal wells with effective screen lengths of 1,000 feet of slotted HDPE pipe, spaced 1,000 feet apart, and requiring approximately 180 horizontal wells. The horizontal wells would be placed at the base of the shallow groundwater system directly above the Navarro Formation (assumed to be 40 feet bgs). Local geology and irregularities in the Navarro Group topography may require installing horizontal wells in multiple smaller sections.

Each horizontal well would pump about 80 gpm for a total of about 21 mgd of groundwater. The trench is assumed to produce 400 gpm for a total of about 0.6 mgd of groundwater.

The trench along the bank of the San Antonio River would be 2,000 feet long, five feet deep, with a slotted HDPE pipe placed along its base. The trench would be backfilled with 15 feet of gravel and then covered with native soils.

Extracted groundwater would travel through an extensive piping network to 45 aboveground treatment plants, with each plant capable of treating the discharge from approximately four wells (about 0.5 mgd). The treatment plants would be located on nonresidential lots whenever possible. It has been assumed that these lots for the treatment plants would have to be purchased.

Treated groundwater would travel through another extensive piping network to a series of horizontal injection wells that would be constructed identical to the horizontal extraction wells. For this evaluation, it was assumed that 180 horizontal injection wells would be needed to reinject the treated groundwater.

Whenever possible, the wells and piping would be installed under roadways to minimize disruption to private land and daily traffic from road closures during construction and operation.

Actual design of the systems described for this CMA would take up to two years to complete. Once designed, the systems would take up to four years to construct. During construction, some dust and construction waste can be expected along with a moderate-to-high level of construction noise and a high level of traffic disruption.

Once implemented, operating and maintaining the systems would cause traffic disruption. For this evaluation, it was assumed that the reinjection wells would require frequent cleaning (due to plugging) using jet rod cleaning methods. As a result, moderate-to-high maintenance disruptions (e.g., access to properties) and associated noise may be expected.

7.6.5.3 Treatment and Disposal

Using this CMA, extracted groundwater would be treated to MCL standards using UVOX technology. The treated groundwater would be reinjected into the shallow groundwater system. Since it will be difficult to reinject all of the treated water, some of it may be discharged to the storm sewer system.

7.6.6 CMA C1: Pump and Treat Plumewide Down the Centerline of the Plume, Reinjection, and Monitored Natural Attenuation

This CMA includes a plumewide pump and treat system with a groundwater extraction trench placed along the bank of the San Antonio River. Horizontal extraction wells with 1,000 feet of slotted HDPE would be placed every 2,400 feet down the centerline of the plume.

Extraction wells would be placed between the horizontal wells to inject treated groundwater into the shallow groundwater. The centerline will contain the highest concentrations of chemical compounds within the plume and presumably where the most groundwater can be extracted. **Figure 7.7** provides a conceptual layout of this CMA.

Reinjecting the treated groundwater was included as an option for disposal and restoration. For this evaluation, it was assumed that reinjecting the treated groundwater would be fairly simple to perform. Potential technical hurdles, such as, plugging of injection wells are associated with reinjection.

7.6.6.1 General Technology Description

The pump and treat strategy contains and treats contaminated groundwater. It involves pumping groundwater from the subsurface and treating the water above ground. After enough of the groundwater is pumped out of the ground, the contaminants begin to be flushed from the aquifer. Groundwater can be pumped from vertical wells, from horizontally drilled wells, or from trenches. The well spacing depends on geologic and

hydrogeologic conditions in the aquifer, the availability of land, reasonable achievable timeframes.

The water pumped from the ground is treated through a water treatment system, such as air strippers, carbon filters, or an UVOX system. The treated water can then be discharged to a sanitary or storm sewer or surface water body. It may also be reinjected into the ground. Reinjection may speed the flushing of the contaminants from the ground, but it may be difficult to operate due to plugging of the reinjection wells. Furthermore reinjecting treated groundwater requires double the level of effort without doubling the effectiveness.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.6.2 Conceptual Design: Horizontal Extraction Well Systems

Approximately 19 horizontal wells with effective screen lengths of 1,000 feet of slotted HDPE would be spaced every 2,400 feet in the gravel filled Navarro Troughs that exist down the centerline of the plume. Local geology and irregularities in the Navarro Group topography may require installing horizontal wells in multiple smaller sections. For this evaluation, it was assumed that this depth would be 40 feet bgs. Horizontal wells may be installed in smaller separate sections, depending upon the local geology and Navarro Group topography.

Each horizontal well would pump about 60 to 80 gpm for a maximum withdrawal of about 2.2 mgd of groundwater. The trench is assumed to produce 400 gpm for a total of about 0.6 mgd of groundwater.

The trench along the bank of the San Antonio River would be 2,000 feet long, 25 feet deep, with a slotted HDPE pipe placed along the base of the trench. The trench would be backfilled with 15 feet of gravel and covered with native soils.

Extracted groundwater would travel through an extensive piping network to five aboveground treatment plants capable of treating the discharge from approximately four wells (about 0.5 mgd). The treatment plants would generally be located on nonresidential lots whenever possible. It has been assumed that these lots for the treatment plants would have to be purchased.

Treated groundwater would travel through another extensive piping network to a series of 19 horizontal injection wells that would be constructed identically to the horizontal extraction wells.

Whenever possible, the wells and piping would be installed under roadways to minimize disruption to private land and daily traffic from road closures during construction and operation.

Actual design of the systems described for this CMA would take up to one year to complete. Once designed, the systems would take up to two years to construct. During construction, low levels of dust and construction waste can be expected, with moderate-to-high levels of construction noise and traffic disruption.

Once implemented, operating and maintaining the systems would cause little traffic disruption. For this evaluation, it was assumed that the reinjection wells would require frequent cleaning (due to plugging) using jet rod cleaning methods. As a result, moderate to high maintenance disruptions (e.g., access to properties) and associated noise may be expected.

7.6.6.3 Treatment and Disposal

Extracted groundwater would be treated to MCL standards using UVOX technology. The treated groundwater would be reinjected into the shallow groundwater system. Since it may be difficult to reinject all of the treated water, some of it may be discharged to the storm sewer system.

7.6.7 CMA D: Existing Source Control Systems and Monitored Natural Attenuation

This CMA includes using the existing source control systems and MNA throughout the contaminated area. **Figure 7.7** provides a conceptual layout of this CMA.

7.6.7.1 General Technology Description

The current source control systems at the MP Site consist of a slurry wall surrounding the entire MP Site source area and extraction wells along the base perimeter between the MP Site source area and off base. The current source control system at Zone 4 consists of horizontal and vertical extraction wells along its entire southern and eastern boundaries.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that “will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem.”

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.7.2 Conceptual Design

The design and construction for the existing source treatment was completed in December 1999. In addition to these measures, this CMA would include MNA.

It has been assumed that 50 new monitoring wells would be installed and that 125 monitoring wells would be sampled annually for VOCs and natural attenuation indicator parameters. It has been assumed the new monitoring wells would be constructed of 20 feet of polyvinyl chloride (SS) casing and 10 feet of SS screen. Whenever possible, the additional monitoring wells would be installed under roadways to minimize disruption to private land and daily traffic from road closures during construction and operation.

A minimal amount of time would be required for designing and installing the additional monitoring wells since all other systems are already operational. During construction, a few disturbances off base can be expected.

Once implemented, operating and maintaining the systems would cause few traffic disruptions. Low noise levels or other disruptions are expected during operation and maintenance.

7.6.7.3 Treatment and Disposal

Because this technology treats the contaminated water underground, there are no aboveground treatment plants, other than existing plants, and no water disposal issues.

7.6.8 CMA E: Flow-Through Reactive Walls or Injected Treatment Zones Plumewide and Monitored Natural Attenuation

This CMA includes using reactive walls or injected treatment zones applied plumewide and along the bank of the San Antonio River. **Figure 7.6** provides a conceptual layout of this CMA.

7.6.8.1 General Technology Description

Reactive walls, or treatment walls, are structures installed underground to treat contaminated groundwater.

First, a trench is constructed across the flow path of contaminated groundwater. The trench is then filled with a material chosen specifically to treat the types of contaminants found at a site. As the contaminated groundwater flows through the treatment wall. They change into less toxic or nontoxic substances.

For chlorinated solvents, iron filings are the most commonly used treatment material. The iron filings will chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene.

Reactive walls can effectively treat the water that passes through them, but they cannot treat pollutants that are already downstream. These dissolved pollutants, however, eventually will be flushed out by the clean, treated water that has passed through the wall. By placing many parallel walls in a contaminated area, it may be possible to hasten the cleanup of the entire area.

Injected treatment zones are installed underground to treat the contaminated groundwater. A ZVI slurry is used in boring injection points every 20 to 30 feet. The injections would treat approximately a 20 to 30 radius around each injection point. As the groundwater passes through the treatment zone the iron slurry chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene. This technique does not require any trenching.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The NCP, the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.8.2 Conceptual Design: Reactive Walls or Treatment Zones

Using CMA E, plumewide treatment would be performed. To achieve this goal, it has been assumed that a reactive wall or treatment zone would need to be spaced every 5,000 feet. Nine walls/treatment zones would be installed. In addition to these nine walls/zones, one wall or treatment zone would be placed at the San Antonio River to treat any contamination that might have bypassed the other walls/zones before flowing into the river.

For this evaluation, it has been assumed that a trench reaching the top of the Navarro Clay (assumed to be 40 bgs) using conventional earth-working equipment. It has been assumed that each trench would be 1,000 feet long and two feet wide. The trenches would then be backfilled with iron filings from the base of the trench to a depth of two to three feet above the saturated gravel and sands (assumed to be 20 feet bgs) and backfilled with native soils (sand). Complete street reconstruction would be necessary for those streets containing reactive walls.

It was assumed that whenever possible, the walls would be installed under roads in an attempt to minimize disruption to private land and daily traffic due to road closures during construction and operation.

If injected treatment zones are installed to treat the contaminated groundwater. A ZVI slurry is used in boring injection points every 20 to 30 feet. The injections would treat approximately a 20- to 30-foot radius around each injection point. As the groundwater passes through the treatment zone the iron slurry chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene. This technique does not require any trenching.

It may be expected that the actual design of the systems described for this CMA would take up to two years to complete. Once designed, it has been assumed the systems would take up to two years to construct. During construction, it may be expected that there would be a large amount of construction waste and high amounts of dust, construction noise, and traffic disruption.

Once implemented, it has been assumed that operating and maintaining the systems would cause some traffic disruption and noise.

7.6.8.3 Treatment and Disposal

Because the reactive walls would treat the contaminated water underground, there are no aboveground treatment plants or water disposal issues.

7.6.9 CMA E1: Plumewide Reactive Walls Down Centerline of Plume and Monitored Natural Attenuation

This CMA includes using the 1,000-foot reactive walls applied plumewide and along the bank of the San Antonio River. The walls would be placed every 4,800 feet down the centerline of the plume in the gravel-filled Navarro Troughs. The centerline of the plume is the thickest area of gravel that has filled Navarro Troughs. This is where the greatest amount of groundwater can be extracted and where contaminant concentrations are the highest and quickest moving through the shallow groundwater. **Figure 7.7** provides a conceptual layout of this CMA, and some of the major criteria used to evaluate each CMA.

7.6.9.1 General Technology Description

Reactive walls, or treatment walls, are structures installed underground to treat contaminated groundwater. They are put in place by constructing a trench across the flow path of contaminated groundwater. The trench is then filled with a chosen material based on the types of contaminants found. As the contaminated groundwater flows through the treatment wall, the contaminants are chemically changed into less toxic or nontoxic substances.

For chlorinated solvents, iron filings are the most commonly used treatment material. The iron filings chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene.

Reactive walls effectively treat the water that passes through them but cannot treat pollutants that are already downstream. However, the clean, treated water that has passed through the wall will eventually flush out these dissolved pollutants. By placing many parallel walls in a contaminated area, it may be possible to hasten the clean up of the entire area.

Injected treatment zones are installed underground to treat the contaminated groundwater. A ZVI slurry is used in boring injection points every 20 to 30 feet. The injections would treat approximately a 20- to 30-foot radius around each injection point. As the groundwater passes through the treatment zone the iron slurry chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene. This technique does not require any trenching.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that “will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem.”

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.9.2 Conceptual Design: Reactive Walls

Plumewide treatment would be performed. To achieve this goal, 11 reactive walls would need to be spaced every 4,800 feet. In addition to these walls, two walls would be placed at the San Antonio River to treat contamination that bypassed other walls before flowing into the river.

For this evaluation, it was assumed that a trench would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs) using conventional earth-working equipment. Each trench would be 1,000 feet long and 2 feet wide. The trenches would be backfilled with iron filings from the base to a depth of two to three feet above the saturated gravel and sand (assumed to be 20 feet bgs). The remainder of the trench would be backfilled with native soils (sand). Complete street reconstruction would be required for those streets containing reactive walls.

Whenever possible, the walls would be installed under roadways to minimize disruption to private land and daily traffic from road closures during construction and operation.

Designing the systems for this CMA would take up to two years to complete. Once designed, the systems would take up to two years to construct. During construction, a large amount of waste and high amounts of dust, construction noise, and traffic disruption can be expected.

If injected treatment zones are installed to treat the contaminated groundwater. A ZVI slurry is used in boring injection points every 20 to 30 feet. The injections would treat approximately a 20- to 30-foot radius around each injection point. As the groundwater passes through the treatment zone the iron slurry chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene. This technique does not require any trenching.

Once implemented, operating and maintaining the systems would cause minor traffic disruption and some noise. However, it is possible that maintaining the walls could include complete reconstruction.

7.6.9.3 Treatment and Disposal

Because the reactive walls would treat the contaminated water underground, there are no aboveground treatment plants or water disposal issues.

7.6.10 CMA F: Limited Number of Reactive Walls and Monitored Natural Attenuation

This CMA includes reactive walls applied specifically to areas of the plume with TCE concentrations in groundwater at or above 100 ppb along with MNA throughout the contaminated area. **Figure 7.7** provides a conceptual layout of this CMA.

7.6.10.1 General Technology Description

Reactive walls, or treatment walls, are structures installed underground to treat contaminated groundwater. They are put in place by constructing a trench across the flow path of contaminated groundwater. The trench is then filled with a chosen material based on the types of contaminants found. As the contaminated groundwater flows through the treatment wall, the contaminants are chemically changed into less toxic or nontoxic substances.

For chlorinated solvents, iron filings are the most commonly used treatment material. The iron filings chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene.

Reactive walls effectively treat the water that passes through them but cannot treat pollutants that are already downstream. However, the clean, treated water that has passed through the wall will eventually flush out these dissolved pollutants. By placing many parallel walls in a contaminated area, it may be possible to hasten the clean up of the entire area.

Injected treatment zones are installed underground to treat the contaminated groundwater. A ZVI slurry is used in boring injection points every 20 to 30 feet. The injections would treat approximately a 20- to 30-foot radius around each injection point. As the groundwater passes through the treatment zone the iron slurry chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene. This technique does not require any trenching.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The NCP, the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.10.2 Conceptual Design: Reactive Walls

Using CMA F, reactive walls would be installed in areas of the plume where TCE is found at or above 100 ppb. To achieve this, it has been assumed four reactive walls would be needed. It has been assumed these walls spaced every 5,000 feet would be needed.

A trench would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs) using conventional earth-working equipment. Each trench would be 1,000 to 2,500 feet long and 0.5 feet wide. The trenches would be backfilled with iron filings from the base to a depth of 2 to 3 feet above the saturated gravel and sand (assumed to be 20 feet bgs). The remainder of the trench would be backfilled with native soils (sand).

Whenever possible, the walls would be installed under roadways to minimize disruption to private land and daily traffic from road closures during construction and operation.

It has been assumed that 50 new monitoring wells would be installed and that 125 monitoring wells would be sampled annually for VOCs and natural attenuation indicator parameters. It has been assumed the new monitoring wells would be constructed of 20 feet of SS casing and 10 feet of SS screen. Whenever possible, the additional monitoring wells would be installed under roadways to minimize disruption to private land and daily traffic from road closures during construction and operation.

Designing the systems for this CMA would take up to one year to complete. Once designed, the systems would take up to one year to construct. During construction, some construction waste and moderate-to-high levels of dust, construction noise, and traffic disruption can be expected.

If injected treatment zones are installed to treat the contaminated groundwater. A ZVI slurry is used in boring injection points every 20 to 30 feet. The injections would treat approximately a 20- to 30-foot radius around each injection point. As the groundwater passes through the treatment zone the iron slurry chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene. This technique does not require any trenching. Additionally the time to complete the installation would be reduced using this technique.

Once implemented, operating and maintaining the systems would cause little traffic disruption and little noise. However, maintenance of the walls could include complete reconstruction.

7.6.10.3 Treatment and Disposal

Treating the contaminated water is accomplished in the subsurface by the reactive walls. Therefore, there are no aboveground treatment plants and no water disposal issues.

7.6.11 CMA G: Limited Microorganism Breakdown and Monitored Natural Attenuation

This CMA includes enhanced biodegradation applied specifically to areas of the plume with TCE concentrations in groundwater at or above 100 ppb, along with MNA throughout the contaminated area. **Figure 7.6** provides a conceptual layout of this CMA.

7.6.11.1 General Technology Description

Enhanced biodegradation is a treatment process for groundwater contamination. Enhanced biodegradation uses naturally occurring microorganisms (bacteria) to degrade, or break down, hazardous substances into less toxic or nontoxic substances. Microorganisms, just like humans, digest organic substances for nutrients and energy.

To speed up the natural breakdown of fuels or solvents, technologies are available that help create favorable environmental conditions for the microorganisms to digest the contaminants. For chlorinated solvents, two types of enhanced biodegradation can be used; aerobic cometabolism and anaerobic reductive dehalogenation. With aerobic cometabolism, other organic compounds (such as methane or propane) are injected into the groundwater along with oxygen to accelerate the biodegradation of the chlorinated solvents. The microorganisms digest and grow using the added organic compounds. They digest the chlorinated solvents when the added organic compounds are gone.

With anaerobic reductive dehalogenation, more complex organic compounds (e.g., vegetable oil or molasses) are added without oxygen. The microorganisms digest the complex organics and use up any remaining oxygen. Under these conditions, the microorganisms may respire ("breathe") the chlorinated solvents, since oxygen is not present. The chlorine atoms are removed from the chlorinated compounds in steps and the eventual result is harmless ethene. However, during the process, byproducts may accumulate from the degradation of TCE. These byproducts include DCE and vinyl chloride. The byproducts themselves will eventually be degraded.

To be effective, both enhanced biodegradation processes require that relatively large amounts of the organic supplements be injected into the ground. Injection wells typically must be placed every 50 feet or less. The organic compounds must be reinjected every six months, and the entire process can take up to two years to complete.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan

(NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.11.2 Conceptual Design: Enhanced Anaerobic Breakdown

Using CMA G, vegetable oil would be injected into the shallow groundwater system. To achieve plumewide treatment using this method, it has been assumed that approximately 3,500 injection wells would be needed. These wells are assumed to be placed on a 50-foot grid to deliver the organic material to microorganisms in the aquifer in areas of high concentrations. Injection of the organic material would occur every six months for three years (total of six injections) to provide enough material to effectively degrade the contaminants.

The injection wells would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs). Each well would be constructed of 10 feet of SS screen and 20 feet of SS casing. Wells would be installed on 50-foot centers since spacing greater than 50 feet is assumed to render this technology ineffective.

It has been assumed that 50 new monitoring wells would be installed and that 125 monitoring wells would be sampled annually for VOCs and natural attenuation indicator parameters. It has been assumed the new monitoring wells would be constructed of 20 feet of SS casing and 10 feet of SS screen. Whenever possible, the additional monitoring wells would be installed under roadways to minimize disruption to private land and daily traffic from road closures during construction and operation.

Designing the systems for this CMA would take one year to complete. Once designed, the systems would take up to two years to construct. During construction, there would be little construction waste, moderate-to-high levels of dust, and a high level of construction noise and traffic disruption.

Once implemented, operating and maintaining the systems would cause moderate-to-high noise levels, many traffic disruptions, and maintenance disruptions (e.g., access to properties).

7.6.11.3 Treatment and Disposal

Because natural biodegradation processes treat the contaminated water underground, there are no aboveground treatment plants and no water disposal issues.

7.6.12 CMA H: Limited Oxygen Treatment and Monitored Natural Attenuation

This CMA includes oxygen treatment (in situ oxidation) using potassium permanganate applied specifically to those areas of the plume with TCE concentrations in groundwater at or above 100 ppb, and MNA throughout the contaminated area. **Figure 7.6** provides a conceptual layout of this CMA.

7.6.12.1 General Technology Description

In situ, or in place, oxidation is a technology that uses chemicals to treat contaminated soils and groundwater. The chemicals are injected into the aquifer via wells, and treatment takes place below the ground surface.

Two common compounds used for in situ oxidation are hydrogen peroxide and potassium permanganate. Both can be used to treat the solvents present in shallow groundwater. Once the pollutants come into contact with the oxidizing chemicals, they are turned into carbon dioxide, or less toxic or nontoxic substances, through chemical reactions.

To be effective, in situ oxidation requires that relatively large amounts of oxidizing chemicals be injected into the ground. Injection wells typically must be placed every 50 feet or less to quickly clean up an area. If longer times are acceptable, they may be placed further apart. Typically, the chemicals must be reinjected twice for the process to be effective. The oxidation process can typically be completed in less than six months.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.12.2 Conceptual Design: In Situ Oxidation

Using CMA H, groundwater would be treated in areas of the plume where TCE is found at or above 100 ppb. To achieve this goal, potassium permanganate would be injected into the shallow groundwater system. Potassium permanganate was chosen because it is safer to use than other oxidizing chemicals. Horizontal wells would operate more effectively than vertical wells and to achieve treatment using in situ oxidation, 90 horizontal injection wells would need to be installed every 100 feet in areas of high concentrations.

The horizontal wells would be placed at the base of the shallow groundwater system directly above the Navarro Formation (assumed to be 40 feet bgs.). Each horizontal well would be 1,000 feet long and consist of perforated HDPE pipe.

Aboveground piping networks would connect the injection wells to chemical storage and mixing tanks located at the surface in secured buildings. Each well would have a dedicated tank, resulting in a total of 90 aboveground mixing tanks and secured buildings. Whenever possible, the wells would be installed under roadways in an attempt to minimize disruption to private land and daily traffic from road closures during construction and operation.

It has been assumed that 50 new monitoring wells would be installed and that 125 monitoring wells would be sampled annually for VOCs and natural attenuation indicator parameters. It has been assumed the new monitoring wells would be constructed of 20 feet of SS casing and 10 feet of SS screen. Whenever possible, the additional monitoring wells would be installed under roadways to minimize disruption to private land and daily traffic from road closures during construction and operation.

Designing the systems for this CMA would take up to two years to complete. Once designed, the systems would take up to four years to construct. During construction, there would be little construction waste, low levels of dust, and moderate-to-high levels of construction noise and traffic disruption.

Once implemented, operation and maintenance would cause moderate constant noise, few traffic disruptions and moderate-to-high levels of disruptions (e.g., access to properties).

7.6.12.3 Treatment and Disposal

Because in situ oxidation treats contaminated water underground, there are no aboveground treatment plants and no water disposal issues. But as stated above, there are aboveground storage and mixing tanks located in secured buildings.

7.6.13 CMA I: Limited Air Injection/Vapor Removal and Monitored Natural Attenuation

This CMA includes air injection and vapor removal applied specifically to those areas of the plume with TCE concentrations in groundwater at or above 100 ppb along with MNA plumewide. **Figure 7.6** provides a conceptual layout of this CMA.

7.6.13.1 General Technology Description

Air injection (AS) with vapor removal is a simple process that physically separates contaminants from groundwater by turning them into vapors or gases and then collecting them. AS means pumping air into the ground below the water table; the air then rises up through the groundwater and pulls the pollutants out of the water. The vapors and gases are collected by applying a vacuum through a system of underground wells above the water table. This system is called SVE.

AS/SVE systems are used for contaminants that have a tendency to evaporate easily. The contaminants found in shallow groundwater are VOCs and evaporate easily.

AS is accomplished through a series of injection wells that are drilled to below the water table. These wells are placed 15 to 50 feet apart. Air piping must run from an air compressor to each injection well. The SVE wells are similar although they are not drilled to below the water table. Soil vapors are purged from the SVE wells and treated at a treatment plant located on the ground surface. Treatment plants may treat the vapors using carbon adsorption, or burning (incineration or catalytic oxidation). The treatment plant and air compressors will be located throughout the area to be treated.

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP), the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem."

MNA involves sampling, active monitoring, modeling, and evaluating containment reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

In some cases, MNA may reduce the risk to human health and the environment by reducing or preventing contamination. Natural attenuation may include any or all of the following processes:

- Biodegradation
- Dispersion
- Dilution
- Sorption
- Volatilization

7.6.13.2 Conceptual Design: Air Sparging/Soil Vapor Extraction

Using CMA I, an AS/SVE system consisting of both air injection wells and SVE wells would be included. Air injection wells would be spaced evenly every 60 feet and the SVE vacuum wells would be evenly spaced every 100 feet in high concentration areas. Based on this assumed spacing, approximately 5,000 wells would be required. Wells would be constructed to the top of the Navarro Clay (assumed to be 40 feet bgs). Each well would be constructed of SS screen and casing.

Extensive piping networks would connect the AS wells to air compressors located on the surface. Air would travel underground through this piping where it would bubble up through the shallow groundwater and volatalize contaminants before being captured by the SVE wells. There would also be piping connecting the SVE wells to air treatment plants. Granulated activated carbon would be used to clean the contaminants from the extracted air. It has been assumed that ten aboveground treatment plants would be needed. For AS/SVE to perform effectively, the wells would be installed on 60- and 100-foot centers.

It has been assumed that 50 new monitoring wells would be installed and that 125 monitoring wells would be sampled annually for VOCs and natural attenuation indicator parameters. It has been assumed that the new monitoring wells would be constructed of 20 feet of SS casing and 10 feet of SS screen. Whenever possible, the additional monitoring wells would be installed under roadways to minimize disruption to private land and daily traffic from road closures during construction and operation.

Designing the systems for this CMA would take up to two years to complete. Once designed, the systems would take at least four years to construct. During construction, there would be some construction waste, moderate-to-high levels of dust, and a high level of construction noise and traffic disruption.

Once implemented, operating and maintaining the systems would cause moderate-to-high levels of noise, traffic disruption, and maintenance disruptions (e.g., access to properties).

7.6.13.3 Treatment and Disposal

With AS/SVE systems, groundwater is treated *in situ* by air volatilizing the contaminants, but the air must then be treated before discharge. This is accomplished by flowing the air through granulated activated carbon, which traps the contaminants. The clean air can then be discharged directly. Spent activated carbon canisters must be disposed properly.

7.6.14 Projected Cleanup Times

Modeling of the estimated cleanup times of the six most promising options was completed. **Table 7.7** compares the estimated 98-percent cleanup times for TCE for each of the most promising CMAs. The computer modeling report is attached in **Appendix A** (HGL, 2001). Select figures from the attached modeling report will be presented in subsequent subsections for the six most promising CMAs.

TABLE 7.7
Estimated Cleanup Times for TCE
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Corrective Measure Alternative	Current	After 5 years	After 10 years	After 15 years
A1: Pump and treat with horizontal wells down centerline of plume lobes	0%	58%	88%	98%
B: Pump and treat at areas of higher concentration with phytoremediation	0%	39%	76%	97%
C1: Pump and treat down centerline of plume lobes with reinjection	0%	59%	87%	98%
D: Existing source control systems	0%	24%	55%	95%
E1: Flow-through reactive walls or treatment zones down centerline of plume lobes	0%	37%	79%	98%
F: Flow-through reactive walls or treatment zones at areas of higher concentration	0%	41%	81%	98%

Notes: These cleanup values do not include the design and construction times. Design and construction times vary from 0 to two years. This is an estimate.

7.6.14.1 CMA A1: Pump and Treat Plumewide Down Centerline of Plume and Monitored Natural Attenuation

CMA A1 includes a plumewide pump and treat system down the centerline of the plume along with a groundwater extraction trench placed along the bank of the San Antonio River. Computer modeling has estimated that after 15 years of operating CMA A1, 98-percent of the current TCE plume would comply with currently accepted drinking water standards. **Figure 7.8** presents the plume morphology for TCE at five-year intervals for CMA A1 as predicted by the computer modeling (HGL, 2001). Additional details and results of the computer modeling effort are located in **Appendix A** (HGL, 2001).

7.6.14.2 CMA B: Limited Pump and Treat, Phytoremediation, and Monitored Natural Attenuation

CMA B includes using pump and treat technology applied specifically to those areas of the plume with PCE or TCE concentrations in the shallow groundwater at or above 100 ppb. Computer modeling has estimated that after 15 years of operating CMA B, 97-percent of the current TCE plume would be below (less than 5 ppb for PCE and TCE) groundwater drinking standards. **Figure 7.9** presents the plume morphology for TCE at five-year intervals for CMA B as predicted by the computer modeling (HGL, 2001). Additional details and results of the computer modeling effort are located in **Appendix A** (HGL, 2001).

7.6.14.3 CMA C1: Pump and Treat Plumewide Down Centerline of Plume, Reinjection, and Monitored Natural Attenuation

CMA C1 includes plumewide pump and treat down the centerline of the plume and reinjection of the treated groundwater. Computer modeling has estimated that after 15 years of operating CMA C1, 98-percent of the current TCE plume would be below (less than 5 ppb for PCE and TCE) groundwater drinking standards. **Figure 7.10** presents the plume morphology for TCE at five-year intervals for CMA C1 as predicted by the computer modeling (HGL, 2001). Additional details and results of the computer modeling effort are located in **Appendix A** (HGL, 2001).

7.6.14.4 CMA D: Existing Source Control Systems and Monitored Natural Attenuation

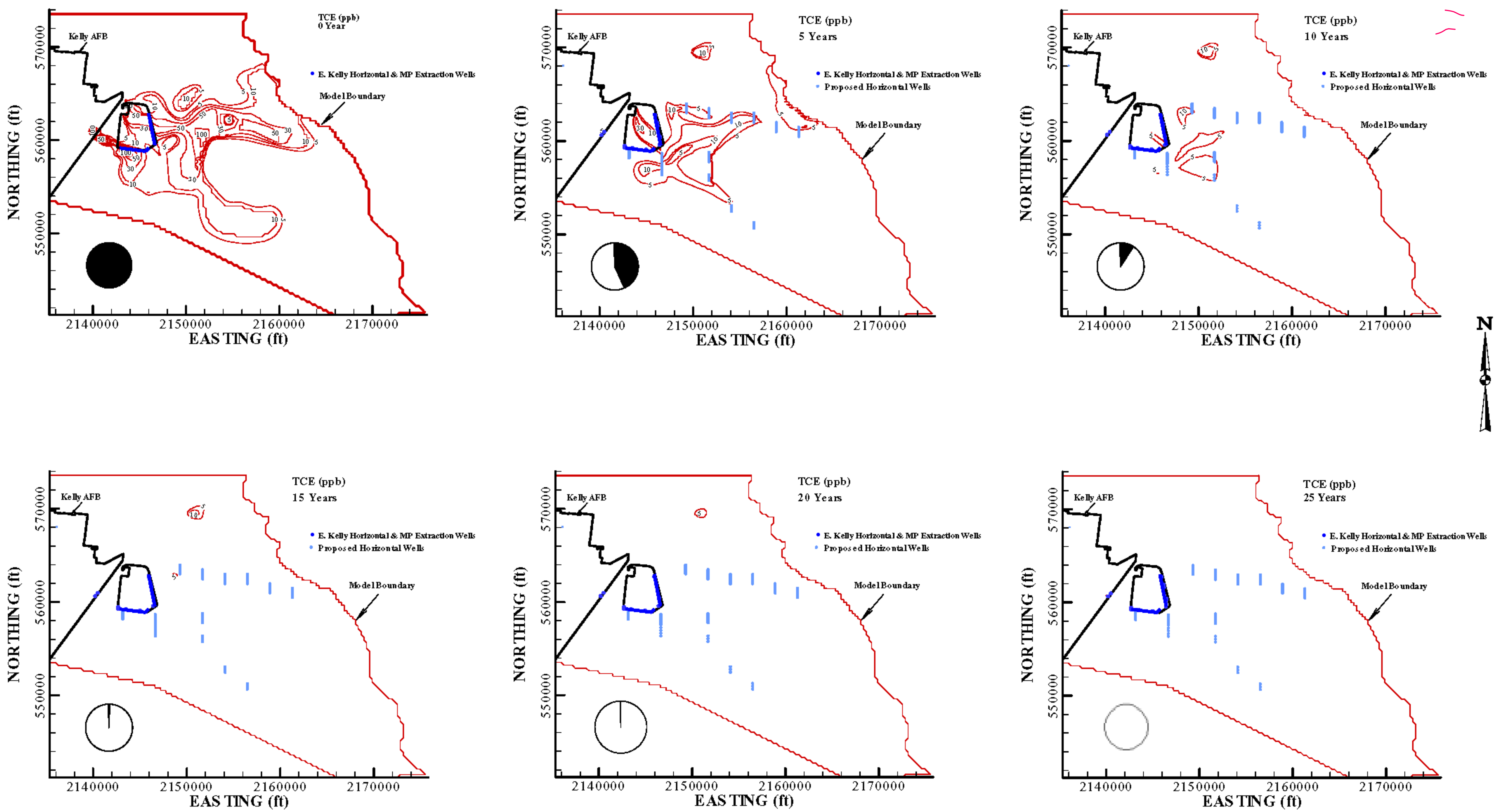
CMA D includes using existing source control systems and MNA throughout the contaminated area. Computer modeling has estimated that after 15 years of operating CMA D, 95-percent of the current TCE plume would be below (less than 5 ppb for PCE and TCE) groundwater drinking standards. **Figure 7.11** presents the plume morphology for TCE at five-year intervals for CMA D as predicted by the computer modeling (HGL, 2001). Additional details and results of the computer modeling effort are located in **Appendix A** (HGL, 2001).

7.6.14.5 CMA E1: Plumewide Reactive Walls Down Centerline of Plume and Monitored Natural Attenuation

CMA E1 includes using reactive walls or treatment zones down the centerline of the plume and along the bank of the San Antonio River. Computer modeling has estimated that after 15 years of CMA E1 operation, 98 percent of the current TCE plume would be below (less than 5 ppb for PCE and TCE) groundwater drinking standards. **Figure 7.12** presents the plume morphology for TCE at five-year intervals for CMA E1 as predicted by the computer modeling (HGL, 2001). Additional details and results of the computer modeling effort are located in **Appendix A** (HGL, 2001).

7.6.14.6 CMA F: Limited Number of Reactive Walls and Monitored Natural Attenuation

CMA F includes using reactive walls or treatment zones applied specifically to those areas of the plume with TCE concentrations in groundwater at or above 100 ppb, and MNA throughout the contaminated area. Computer modeling has estimated that after 15 years of operating CMA F, 98-percent of the current TCE plume would be below (less than 5 ppb for PCE and TCE) groundwater drinking standards. **Figure 7.13** presents the plume morphology for TCE at five-year intervals for CMA F as predicted by the computer modeling (HGL, 2001). Additional details and results of the computer modeling effort are located in **Appendix A** (HGL, 2001).



LEGEND

TCE Contour 5

Existing System

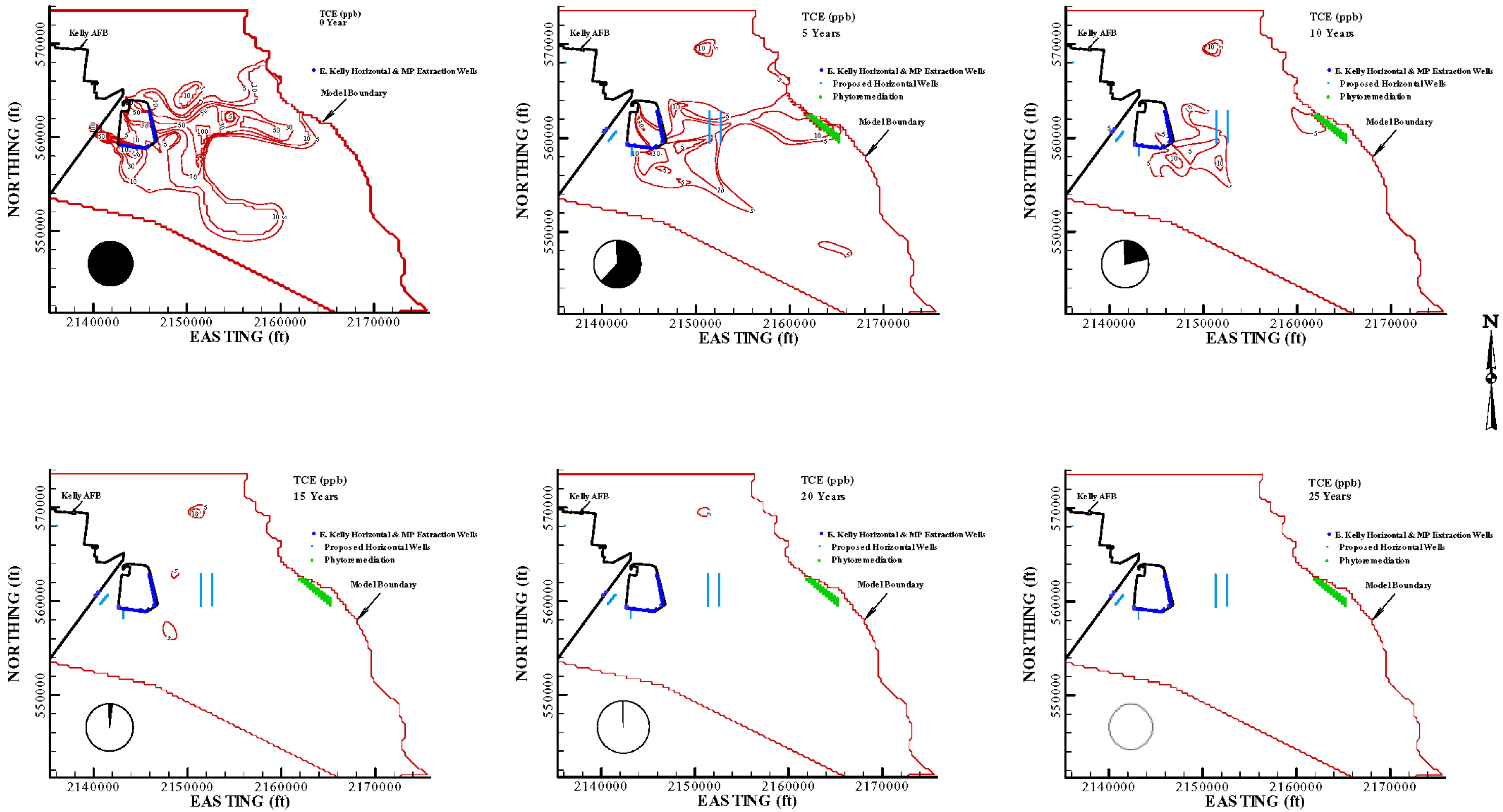
Conceptual Horizontal Wells

NOTE:

Chart shows percent area of the FY2000 plume that remains above MCL. A circle represent 100 % of the area above MCLs, while a completley white circle represent 100 % below MCLs.

FIGURE 7.8
CMA A1: Pump-and-Treat Plumewide Down Certerline of Plume and Natural Attenuation Plume Morphology for TCE at 5-Year Intervals
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL



LEGEND

TCE Contour — 5 —

Existing and Conceptual Horizontal Wells

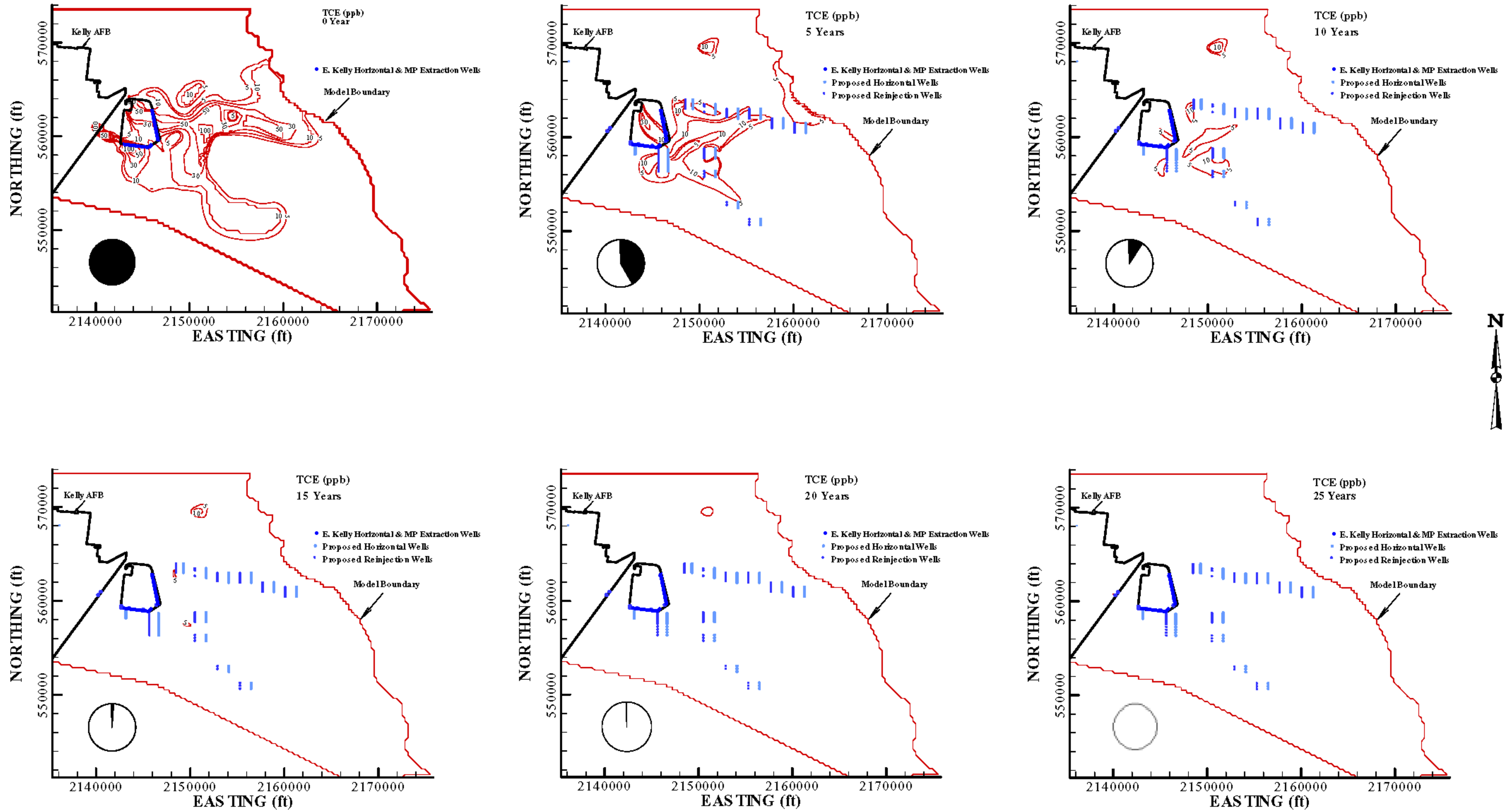
Conceptual Phytoremediation

NOTE:

Chart shows percent area of the FY2000 plume that remains above MCL. A circle represent 100 % of the area above MCLs, while a completely white circle represent 100 % below MCLs.

FIGURE 7.9
CMA B: Limited Pump and Treat with Phytormediation, and Natural Attention:
Plume Morphology for TCE at 5-Year Intervals
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL



LEGEND

TCE Contour — 5 —

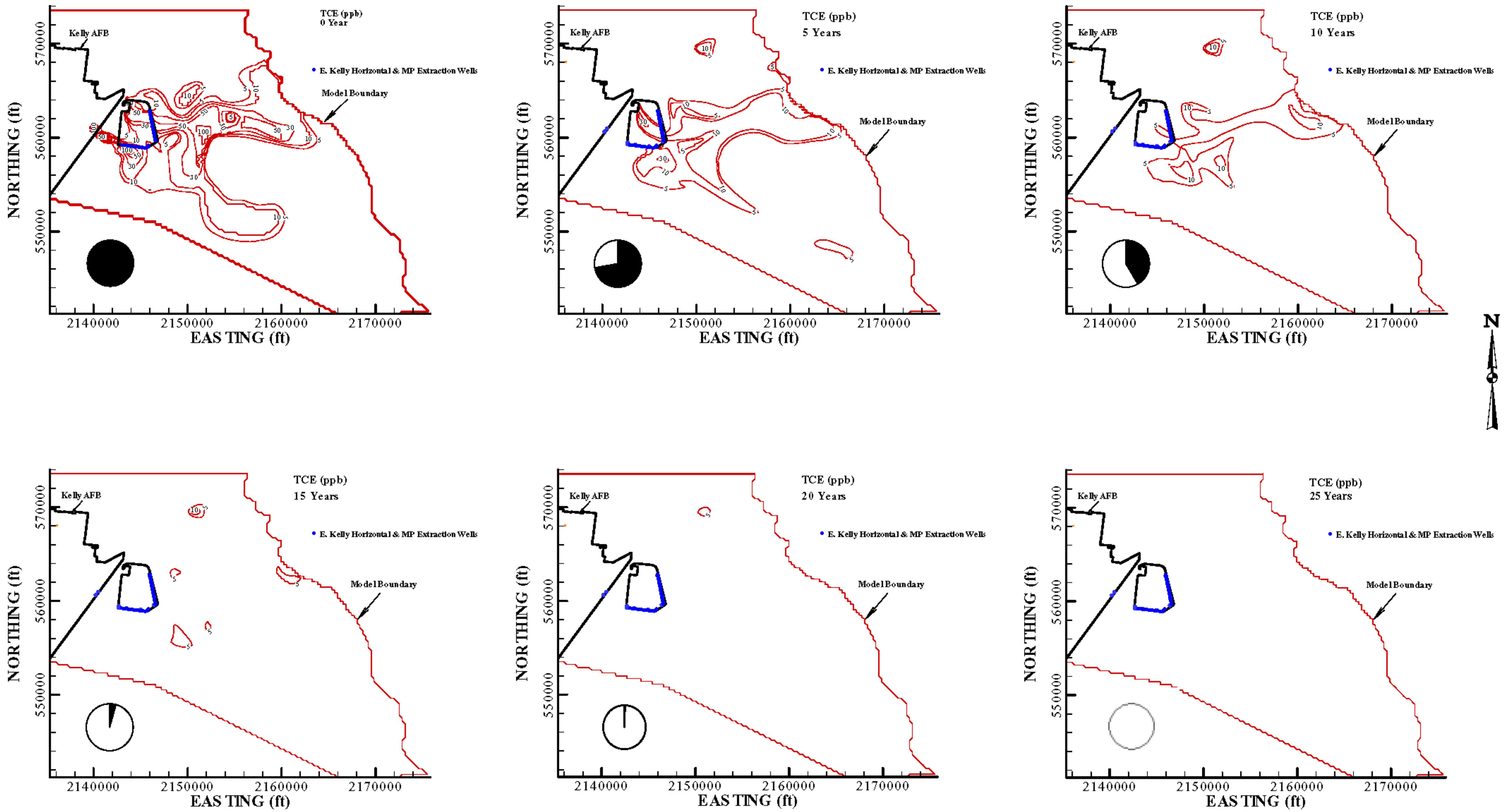
Existing and Conceptual Horizontal Wells

NOTE:

Chart shows percent area of the FY2000 plume that remains above MCL. A circle represent 100 % of the area above MCLs, while a completley white circle represent 100 % below MCLs.

FIGURE 7.10
CMA C1: Pump and Treat Plumewide Down the Centerline of Plume with Reinjection and Monitored Natural Attenuation
Plume Morphology for TCE at 5-Year Intervals
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL



LEGEND

TCE Contour 5

Existing System

NOTE:

Chart shows percent area of the FY2000 plume that remains above MCL. A circle represent 100 % of the area above MCLs, while a completely white circle represent 100 % below MCLs.

FIGURE 7.11

CMA D: Existing Source Control System and Monitored Natural Attention: Plume Morphology for TCE at 5-Year Intervals

Zone 4 CMS Report

Kelly Air Force Base, Texas

CH2MHILL

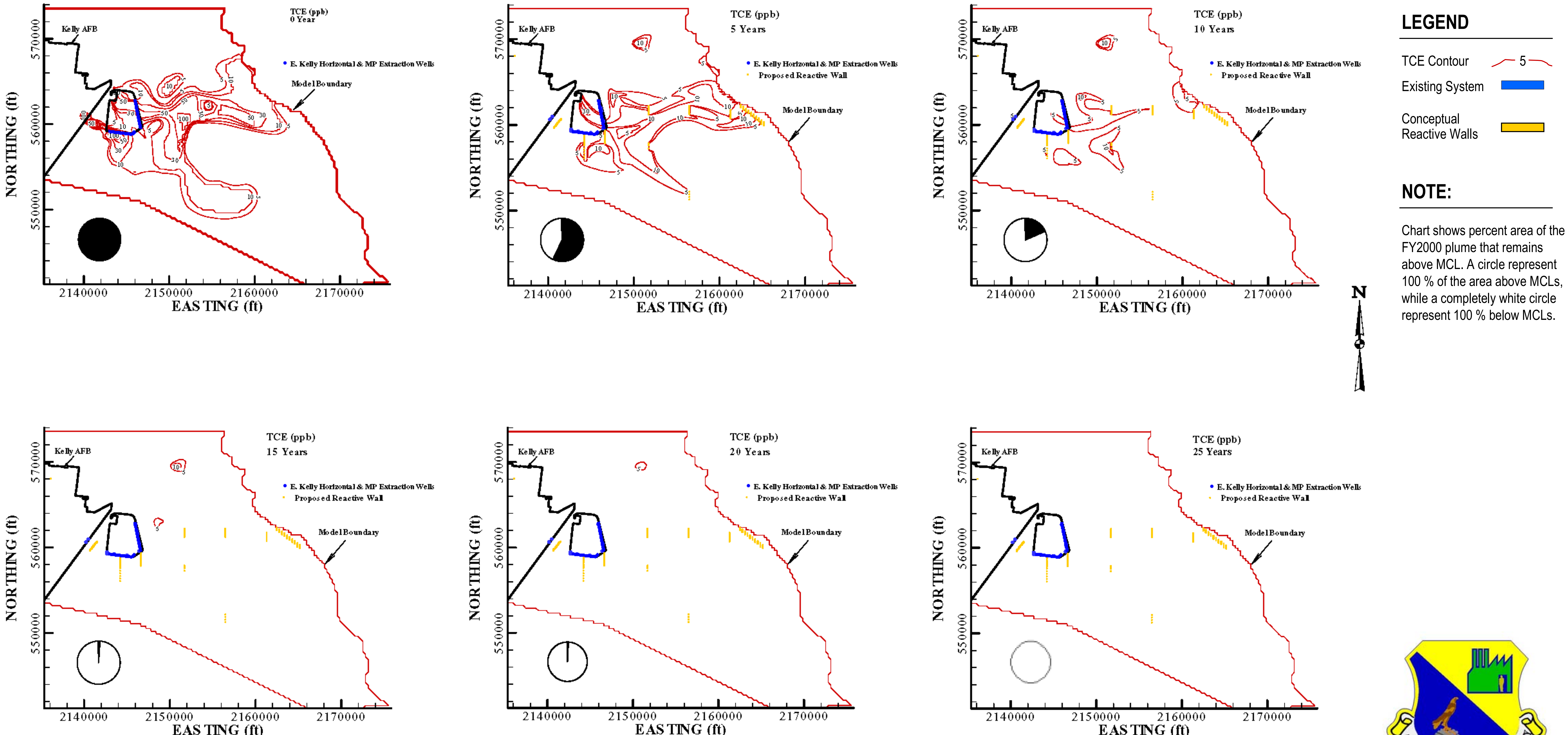
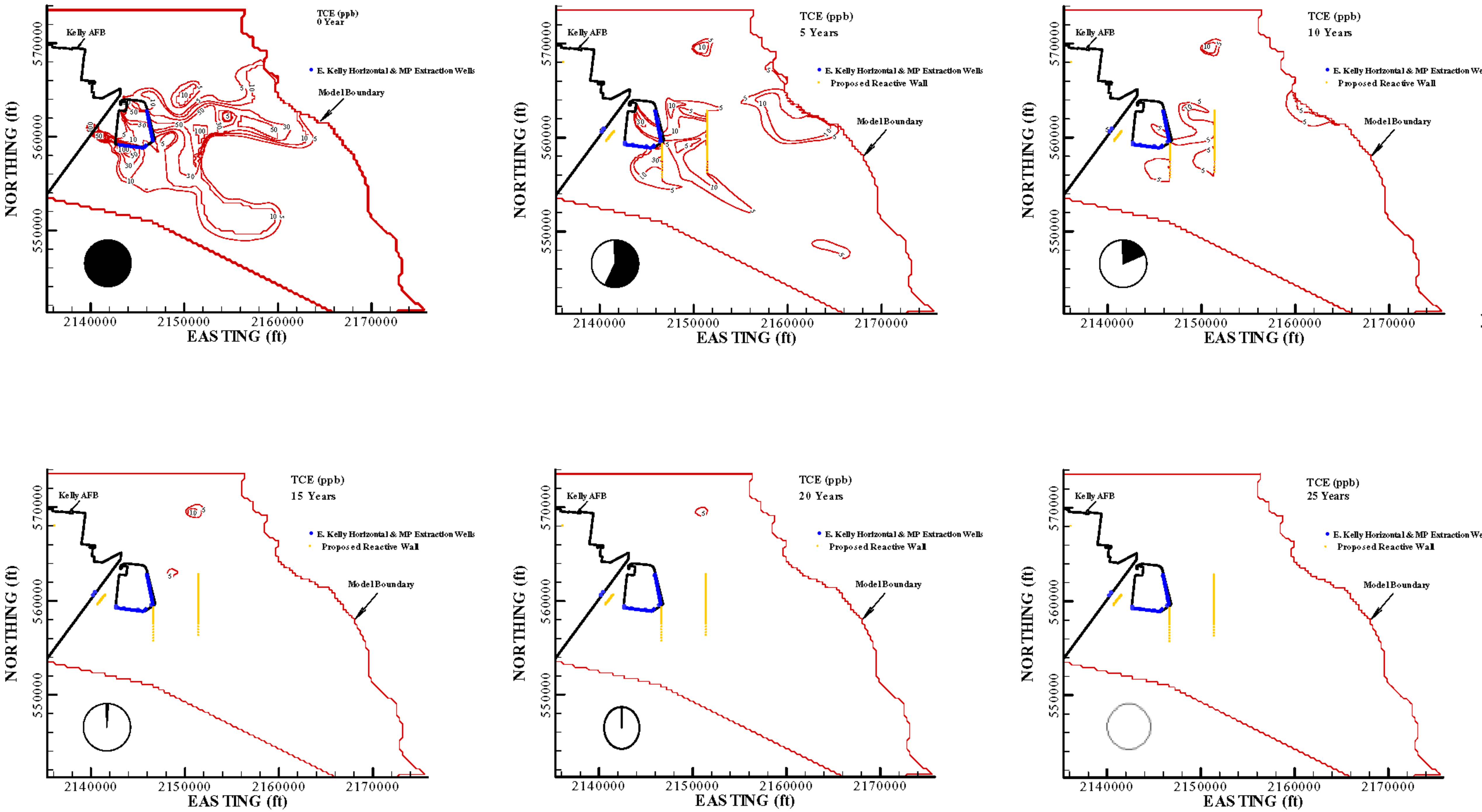


FIGURE 7.12
CMA E1: Plumewide Reactive Walls Down Centerline of Plume and Monitored Natural Attenuation
Plume Morphology for TCE at 5-Year Intervals
Zone 4 CMS Report
Kelly Air Force Base, Texas



LEGEND

TCE Contour — 5 —

Existing System

Conceptual Reactive Walls

NOTE:

Chart shows percent area of the FY2000 plume that remains above MCL. A circle represent 100 % of the area above MCLs, while a completely white circle represent 100 % below MCLs

FIGURE 7.13

CMA F: Limited Number of Reactive Walls and Monitored Natural Attention: Plume Morphology for TCE at 5-Year Intervals

Zone 4 CMS Report

Kelly Air Force Base, Texas

CH2MHILL

SECTION 8.0

Summary of Corrective Measures

This section presents a summary of the evaluation of CMAs for the offsite plumes, and for additional source control at Sites SS051 and MP. The summary briefly reviews the remedial technologies and evaluates each alternative based on community concerns, meeting corrective action objectives and technical specifications. The evaluation summaries include a description and supporting rationale for each alternative. The preferred alternatives for the off-base area, SS051 on-base source area and MP source area are provided.

Twelve CMAs were developed for the off-base solvent plume. The CMAs consist of the following remedial technologies, or a combination of the technologies: pump and treat, reactive walls, in-situ oxidation, air sparging and vapor extraction, enhanced biodegradation, phytoremediation and natural attenuation. Each of the 12 CMAs were evaluated using community concerns and technical criteria. Six of the 12 CMAs were found to meet some or most of the community concerns and technical criteria. The preferred technologies of the six most promising alternatives are briefly reviewed on Section 8.1

Seven CMAs were developed for the on-base MP and SS051 source areas. These CMAs were evaluated using the technical criteria. The CMAs consisted of the following remedial technologies, or a combination of the technologies: pump and treat, reactive walls, in-situ oxidation, air sparging and vapor extraction, enhanced biodegradation and natural attenuation. The preferred alternative is selected in the conclusions section for each site.

8.1 Review of Preferred Technologies

8.1.1 Pump and Treat

Pump and treat (hydraulic containment) strategy extracts groundwater through one or more types of wells and treats the contaminated groundwater in an aboveground treatment plant. After enough of the groundwater is pumped from the ground, the contaminants are flushed from the aquifer.

Groundwater can be pumped from vertical or horizontal wells, or from drain lines. The well spacing depends on geological and hydrogeological conditions in the aquifer, the availability of land and the speed at which the CAOs can be met.

The water pumped from the ground is treated through a water treatment system, such as air strippers, carbon filters or a UVOX system. The treated water can then be discharged to a sanitary or storm sewer or surface body water. It may also be reinjected into the ground. Reinjection may speed the flushing of the contaminants from the ground, but it may be difficult to operate due to plugging of the reinjection wells. Reinjection also requires twice the level of effort without the double benefit.

8.1.2 Flow-Through Reactive Walls (Permeable Reactive Barriers)

In situ, or in place, flow-through reactive walls, or treatment walls, are structures installed underground to treat contaminated groundwater.

Treatment walls are put in place by first constructing a trench across the flow path of contaminated groundwater. The trench is then filled with a chosen material based on the types of contaminants found at a site. As the contaminated groundwater flows through the treatment wall, the contaminants are chemically changed into less toxic or nontoxic substances.

For chlorinated solvents, ZVI is the most commonly used treatment material. The ZVI (typically iron filings) will chemically reduce and strip the chlorines from the solvents, converting them to harmless ethene.

Reactive barriers can effectively treat the water that passes through them, but they cannot treat pollutants that are already downstream. By cutting off the upgradient source, the downgradient-dissolved pollutants will eventually be remediated through natural attenuation.

Reactive Slurry

This technology delivers ZVI into groundwater systems by injecting reactive slurry containing colloidal-sized ZVI, water, and nitrogen gas. The reactive slurry is injected into the aquifer via wells and treatment takes place below the ground surface. The nitrogen gas pressurizes the slurry for injection and maintains subsurface anaerobic conditions to ensure that the ZVI is not oxidized before it is delivered to the target treatment zone. As the contaminated groundwater flows through the treatment zone, the chlorinated solvents are chemically changed into less toxic or nontoxic substances.

For reactive slurry injection to be effective, wells are typically placed every 25 feet or less to clean an area.

8.1.3 Phytoremediation

Phytoremediation uses living plants to clean or remediate sites by removing pollutants from the soil and water. Plants help remove and possibly break down some pollutants, including the solvents found in Zone 4 OU-2 shallow groundwater.

Trees—most commonly poplar trees—are the types of plant most often used for treatment of groundwater contamination. Tree roots grow down to near the water table and withdraw contaminated groundwater. Once in the tree, the pollutants may be degraded in the root zone or released to the atmosphere.

Typically, phytoremediation is most effective at cleaning up sites with shallow groundwater with low to moderate levels of contaminants, since roots have a limited penetration depth. Phytoremediation can be a visually pleasing approach for clean up. A disadvantage of phytoremediation includes time for the trees to reach maturity. Upon planting, the root system does not extend to the groundwater. Root system growth into the aquifer is necessary to promote destruction of the contaminants.

Phytoremediation seems to be a promising technology to help prevent pollutants from spreading into the San Antonio River.

8.1.4 Monitored Natural Attenuation

MNA is a strategy that takes advantage of natural processes to reduce contaminant concentrations. The NCP, the regulatory framework for the Superfund program, defines natural attenuation as a process that "will effectively reduce contaminant toxicity, mobility, or volatility to levels that are protective of human health and the ecosystem." MNA involves sampling, active monitoring, modeling and evaluating contaminant reduction rates to assess the progress of the natural attenuation processes. EPA considers it an acceptable cleanup approach for many sites.

8.2 Summary of Offsite Plume Alternatives

The CMAs were evaluated against community concerns, corrective action objectives, and technical criteria. The off-base CMAs have been presented to the public for input. Based on public input on this information, six corrective measures alternatives were found to be most promising for meeting community concerns, CAOs, and technical criteria. The six most promising alternatives are described below.

8.2.1 Pump and Treat Plumewide Down Centerlines of Plumes

This CMA includes a plumewide pump and treat system with a groundwater extraction trench placed along the bank of the San Antonio River. Horizontal or vertical extraction wells would be placed down the centerline of the plume every 2,400 feet in the gravel-filled Navarro Troughs. The centerline of the plume is the thickest area of gravel that has filled Navarro Troughs; this is where the greatest amount of groundwater can be extracted. Contaminant concentrations are highest and move the quickest through these gravel troughs.

8.2.2 Limited Pump and Treat with Phytoremediation and MNA

This CMA includes using pump and treat technology applied specifically to areas of the plume with TCE concentrations in the groundwater at or above 100 ppb. Phytoremediation along the San Antonio River would be included as part of this CMA.

8.2.3 Pump and Treat Plumewide Down Centerlines of Plumes with Reinjection:

This CMA includes a plumewide pump and treat system with a groundwater extraction trench placed along the bank of the San Antonio River. Horizontal or vertical extraction wells would be placed down the centerline of the plume every 2,400 feet in the gravel-filled Navarro Troughs. The centerline of the plume is the thickest area of gravel that has filled Navarro Troughs; this is where the greatest amount of groundwater can be extracted. Contaminant concentrations are highest and move the quickest through these gravel troughs. The treated extracted groundwater would be re-injected into the shallow aquifer through horizontal or vertical wells.

8.2.4 Existing Source Control Systems and MNA:

This CMA includes using the existing source control systems and MNA throughout the contaminated area.

8.2.5 Plumewide Reactive Walls or Treatment Zones Down Centerline of Plume

This CMA includes using reactive walls or injected treatment zones applied plumewide and along the bank of the San Antonio River.

8.2.6 Limited Number of Reactive Walls or Treatment Zones and MNA:

This CMA includes reactive walls applied specifically to areas of the plume with TCE concentrations in groundwater at or above 100 ppb along with MNA throughout the contaminated area.

8.3 Off-base Corrective Measures Alternatives

Off-base CMAs were weighed using community concerns, CAOs, and technical criteria. The following positive and negative criteria were identified to summarize each alternative:

Positive

- Less disruption to the community and environment during construction
- Less disruption to the community and environment during operation
- Less construction time
- Faster cleanup times during operation
- Technical feasibility
- Little access to private property required

Negatives

- More disruption to the community and environment during construction
- More disruption to the community and environment during operation
- More construction time
- Longer clean-up times during operation
- Non-technical feasibility
- Extensive access to private property required

8.3.1 Pump and Treat Technologies: Alternatives A1, B and C1

The following observations are made regarding the alternatives A1, B and C1. Alternatives A1, B, and C1 include pump and treat technology. The following observations are made for these alternatives:

- All three pump and treat alternatives are considered difficult to construct. Alternative C1 is considered the most difficult of the three to construct. The difficulties associated with constructing and implementing these alternatives are mainly due to the significant surface disruptions in residential areas during construction and the expected long-term need of private land for numerous treatment facilities. Alternative B would be the least difficult to construct, and could be used near the base to take advantage of the existing Zone 4 groundwater treatment plant.

- Since contaminated groundwater would be brought to the surface for treatment, there is the potential contaminated water could leak and impact the surface in residential areas. Also, treated water would need to be disposed of for the life of the system.
- Extensive mechanical systems and instrumentation and controls would be required for these alternatives and reliable operation of these alternatives is dependent on these systems functioning properly. This will require large amounts of time for operation and maintenance of the system. Alternative B could take advantage of existing systems and instrumentation associated with the existing Zone 4 groundwater treatment system.
- Implementing pump and treat technology off site has the potential for drawing contamination from off-base sources into the treatment area. Alternative B could be used only in areas which may not cause the drawing of contamination from off-base areas.
- Pump and treat near the base would be easier to implement since it could be tied into existing systems.

8.3.2 Source Control Systems and MNA: Alternative D

- After 15 years, this alternative is the least likely of the six to achieve cleanup to CAO standards (i.e., 95 percent cleanup versus 97 to 98percent cleanup for the other five alternatives).
- This alternative remediates the smallest percentage of area above MCLs in five and 10 years of the six alternatives.
- This alternative is considered moderately protective of the environment since low-level groundwater contamination could seep into the San Antonio River.

8.3.3 Flow-through Reactive Wall or Treatment Zone Technology: Alternatives E1 and F

- Both alternatives are predicted to achieve 98 percent cleanup of the current area above MCLs after 15 years or less.

- Both alternatives are expected to be difficult to implement using the trenching technique primarily due to the significant surface disruptions (i.e., trenching, excavating, etc.) during implementation; however, Alternative F will cause the least surface impacts of the two alternatives. If injected treatment zones are used the difficulty to implement is greatly reduced since no trenching would be required.

- Time to design and construct Alternative F is expected to be about one to two years less than Alternative E1. If injected treatment zones are used the time to design and construct is expected to be about one year.

- Little operation and maintenance will be required following the completion of the reactive walls or treatment zones.

- No groundwater will be brought to the surface under either alternative.

8.4 Off-base Alternatives Conclusion

Based on the considerations presented above, a combination of Alternatives B (near the base boundary) and F (using a reactive wall or treatment zone) are the best corrective measures alternatives for the off-base plumes at meeting both community concerns and technical criteria. The vertical pump and treat will be utilized in an area near the base since modeling predicts longer cleanup times due to the slow groundwater gradient in this area. Reactive walls or treatment zones will be used to prevent downgradient migration. A conceptual layout of the preferred alternative is shown in **Figure 8.1**. The estimated cost is included in Appendix C. Natural attenuation will also continue for very low down-gradient areas of the current plume. Modeling was conducted for the proposed combination of alternatives B and F. Based on recent modeling, it is predicted that after 14 years or less, 98percent of the offsite groundwater contamination would be remediated to below CAO (MCLs) standards under this combined alternative. Table 8.1 is the modeled estimated cleanup times TCE for the six most promising alternatives and the preferred combination remedial alternative. The model predicts the preferred combination alternative to achieve MCLs the quickest.

The complete combined preferred alternative modeling results are included in Appendix A**.**

TABLE 8.1
Estimated Cleanup Times for TCE
Zone 4 Corrective Measures Study, Kelly Air Force Base, Texas

Corrective Measure Alternative	Current	After 5 years	After 10 years	After 15 years
Preferred Combination Remedial Alternative	0%	65%	94%	99%
A1: Pump and treat with horizontal wells down centerline of plume lobes	0%	58%	88%	98%
B: Pump and treat at areas of higher concentration with phytoremediation	0%	39%	76%	97%
C1: Pump and treat down centerline of plume lobes with reinjection	0%	59%	87%	98%
D: Existing source control systems	0%	24%	55%	95%
E1: Flow-through reactive walls or treatment zones down centerline of plume lobes	0%	37%	79%	98%
F: Flow-through reactive walls or treatment zones at areas of higher concentration	0%	41%	81%	98%

Notes: These cleanup values do not include the design and construction times. Design and construction times vary from zero to two years. This is an estimate.

Under this combined alternative, pump and treat would be implemented near the base boundaries in higher concentration areas. Reactive walls or injected treatment zones would be applied specifically to areas of the plumes with TCE or PCE concentrations in groundwater with higher concentrations. MNA will be used in downgradient areas of low concentrations. Pump and treat will require aboveground treatment plants but upgrades of existing on-base plants will be used. Alternative F does not include any aboveground

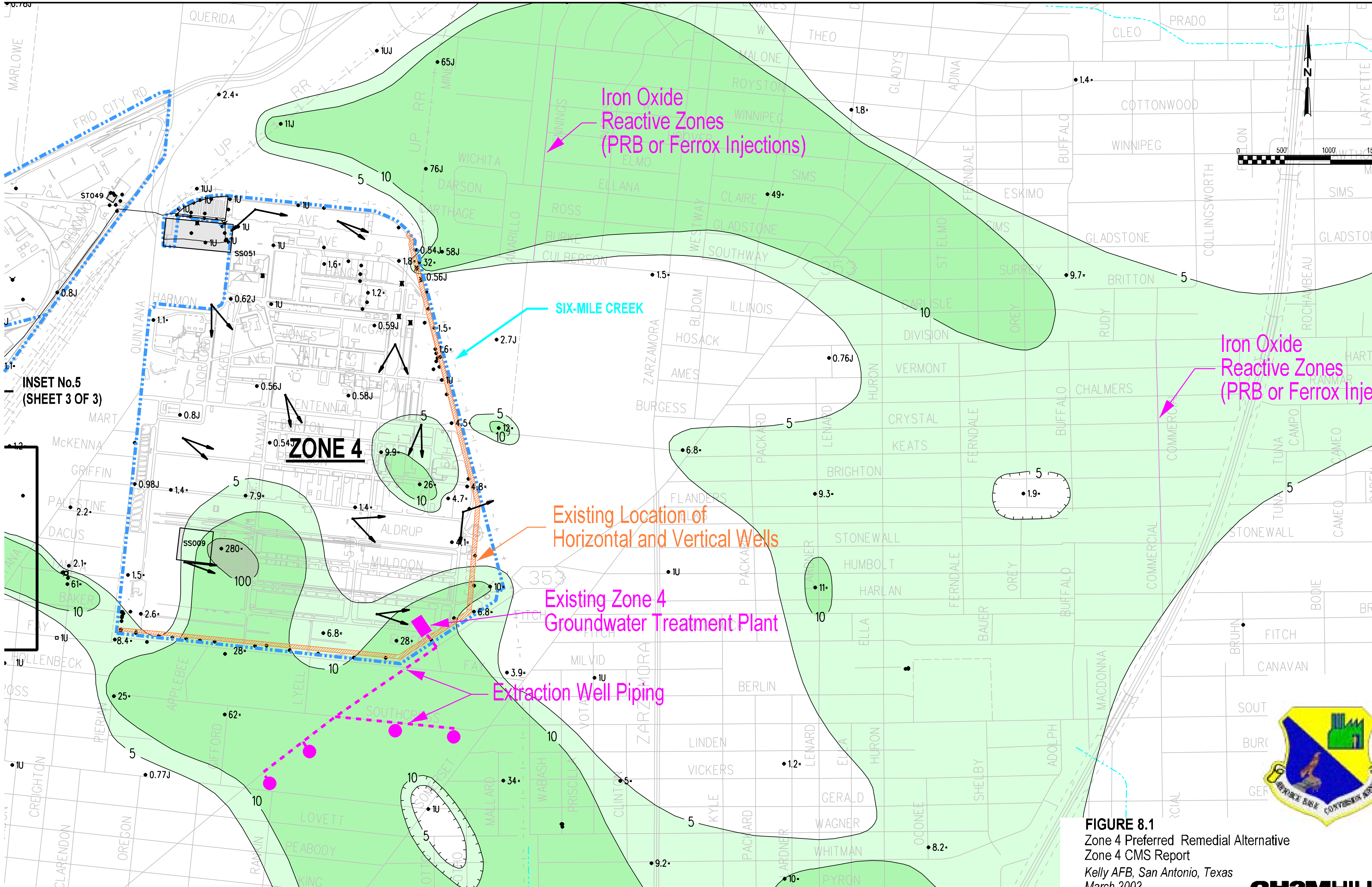


FIGURE 8.1
Zone 4 Preferred Remedial Alternative
Zone 4 CMS Report
Kelly AFB, San Antonio, Texas
March 2002

CH2MHILL

SAN//KELLY/BWC/21c2110-Alter-Fed02.dlv
29-MAR-2002

groundwater treatment. After the initial disturbances associated with construction, operation of Alternative F should cause essentially no impact or risk to residents.

8.5 MP Source Area

As described in Section 7, the technical considerations and modeling results have been presented, and six corrective measures alternatives were found to be most promising for remediating the MP source plume. The following are the six most promising alternatives:

- Alternative 1: Existing Source Control Systems and Monitored Natural Attenuation
- Alternative 2: Existing Source Control with Pump and Treat
- Alternative 3: Flow-Through Reactive Wall
- Alternative 4: Injection of Flow-Through Reactive Barrier
- Alternative 5: Limited Microorganism Breakdown and Monitored Natural Attenuation
- Alternative 6: Limited Oxygen Treatment and Monitored Natural Attenuation
- Alternative 7: Air Injection/Vapor Removal and Monitored Natural Attenuation

8.5.1 Considerations

The following observations are made regarding the seven alternatives for the MP source area plume. Alternatives 1, 2, 3, 5 and 7 are not preferred because of the following:

- Extensive mechanical systems and instrumentation and controls would be required for alternatives 1, 2 and 7 and operation of these alternatives is dependent on these systems functioning properly. This will require large amounts of time for operation and maintenance of the system.
- Alternative 5 (limited micro-organism breakdown)

The remaining alternatives for consideration are Alternatives 3, 4 and 6. Of these three alternatives the following observations are made:

- These alternatives are predicted to achieve cleanup of the current area above MCLs after 15 years or less.
- These alternatives are expected to be implementable.
- Little operation and maintenance will be required following the completion of these alternatives.
- No groundwater will be brought to the surface during the operation of these alternative.
- Alternative 3 is more disruptive during construction.

8.5.2 Preferred Alternative: MP Area Plume

Based on the considerations presented above, Alternative 1 is the preferred corrective measures alternative for the MP source area. This alternative would require monitoring of the existing source control and base boundary systems. The progress of the MNA processes would also be tested throughout the contaminated area.

8.6 Site SS051

As described in Section 7, the technical considerations and modeling results have been presented to the public for input and based on public input on this information, seven corrective measures alternatives were found to be most promising. The following are the seven most promising alternatives:

- Alternative 1: Existing Source Control Systems and MNA
- Alternative 2: Existing Source Control with Pump and treat
- Alternative 3: Flow-Through Reactive Barriers
- Alternative 4: Injection of Flow-Through Reactive Barrier
- Alternative 5: Limited Microorganism Breakdown
- Alternative 6: Limited Oxygen Treatment
- Alternative 7: Air Injection/Vapor Removal and MNA

8.6.1 Considerations

The following observations are made regarding the seven most promising alternatives for the offsite plumes. Alternative 1 involves already existing source control systems with MNA. This alternative is the preferred because of the following:

- Existing and planned interim bio-enhancement and chemical oxidation at the source areas, and other areas of higher concentrations on-base will effectively treat the contaminants.
- Existing pump and treat base boundary systems will prevent further off-base migration of COCs and capture residual concentrations between the source areas and the base boundary.
- MNA will continue to actively lower the COCs from groundwater between the source area alternatives and the base boundary system.

Alternative 2 involves pump and treat technology. This alternative is not preferred because of the following:

- Since contaminated groundwater would be brought to the surface for treatment, there is the potential for contaminated water to leak. Also, treated water would need to be disposed of for the life of the system leading to an increase in long term operation and maintenance costs.
- Extensive mechanical systems and instrumentation and controls would be required for this alternative and reliable operation of this alternative is dependent on these systems functioning properly.

Alternatives 3 and 4 involve flow-through reactive barriers. Of these two methods the following observations were made:

- The time to design and construct these systems is expected to take slightly less time than the other alternatives.
- Minimal operation and maintenance will be required for both alternatives upon completion of the reactive walls.
- No groundwater will be brought to the surface under either alternative.
- Results in destruction of the contaminant mass by converting COCs to non-toxic by-products such as carbon dioxide.
- Provide continued protection against migration of residual CVOCs from the treatment area.
- Alternative 3 is the preferred potential method because it would result in a more continuous remediation barrier than Alternative 4.
- Not a preferred methods for Site SS051 because of the difficulty of implementation caused by buildings and underground utilities in the immediate vicinity of Site SS051.

Alternative 5, Limited Microorganism Breakdown, offers the following observations and is a preferred method at Site SS051 (This alternative is currently being completed as an interim system at the source area, and other areas of higher concentrations.):

- No groundwater will be brought to the surface during the process. As a result there would be no treatment plants or water disposal issues.
- Operational and maintenance costs are low compared with pump and treat systems.
- Easier to implement than reactive barriers at Site SS051 due to the close proximity of buildings and utilities both within and immediately downgradient of the site.

Alternative 6, Limited Oxygen Treatment (in-situ oxidation), offers the following observations and is a potentially preferred method of treatment at Site SS051 (This alternative is currently being completed as an interim system at the source area, and other areas of higher concentrations.):

- Treatment of contaminated groundwater takes place underground using chemicals injected into the groundwater via wells. Aboveground treatment facilities are not necessary.
- Once designed and installed, the oxidation process for treating COCs can potentially be completed in less than six months.
- Results in destruction of the contaminant mass by converting COCs to non-toxic by-products such as carbon dioxide.

Alternative 7, Air Injection with Vapor Removal and MNA, offer the following observations resulting in the potential exclusion as a preferred treatment method.

- Requires multiple aboveground treatment facilities for the vapor extraction process. In addition, substantial air piping and compressors are necessary to ensure adequate treatment. This results in increased noise as well as long term operation and maintenance.
- Soil gas is processed above ground by filtration through canisters containing granulated activated carbon. These canisters have limited life-spans and must be disposed of and replaced on a regular basis for continued functionality of the system.

8.6.2 Preferred Alternative: Site SS051 Source Area

Based on the considerations presented above, Alternative 1 is the preferred corrective measures alternative for the SS051 source area. Under the this alternative, monitoring of the existing source control and base boundary systems would occur. The progress of MNA processes would also be tested throughout the contaminated area.

SECTION 9.0

References

CH2M HILL. 1993. *Remedial Investigation Work Plan, IRP Zone 4, Sites SS051 and SS052*.

CH2M HILL. 1994. *Supplemental Sampling at Site S-7, Kelly AFB, Texas.*

CH2M HILL. 1995a. *Sixmile Creek Surface Water Quality Study, Kelly AFB, Texas.*

CH2M HILL. 1996a. *Site-Specific Environmental Baseline Survey/Southwest Corner of East Kelly.*

CH2M HILL. 1997. *Final Draft DRMO Lot Z04 Closure Investigation Report, Kelly AFB, Texas.*

CH2M HILL. 1997a. *RCRA Closure Investigation for Yard N, Kelly AFB, Texas.*

CH2M HILL. 1997b. *Final RCRA Closure Investigation Report for Yard 13, Kelly AFB, Texas.*

CH2M HILL. 1997c. *Closure Investigation Report, IRP Site SS009*.

CH2M HILL. 1998a. *IRP Zone 4, Focused Feasibility Study for Source Control at Site SS051*.

CH2M HILL. 1998b. *Draft Final Building 3065 Closure Investigation Report, Kelly AFB, Texas.*

CH2M HILL. 1998c. *Design Basis Report for the East Kelly, Boundary Control Groundwater Collection and Treatment System, Kelly AFB, San Antonio, Texas.*

CH2M HILL. 1999. *Closure Plan.*

CH2M HILL, 1999a. *Kelly AFB BRAC Cleanup Plan.*

CH2M HILL, 1999b. *Final Closure Report Building 3096, Kelly AFB, Texas.*

CH2M HILL, in progress. *RFI Report Volume II*.

EA Engineering, Science, and Technology. 1995. *Solid Waste Management Unit Closure Report, Building 3794, Kelly AFB, Texas.*

Engineering Science. 1982. *Installation Restoration Program, Phase I - Records Search, Kelly AFB, Texas.*

Greater Kelly Development Corporation (GKDC). 1997. *Master Plan for the Redevelopment of Kelly Air Force Base*.

HNUS. 1989. *Basewide Hydrogeologic Assessment, Kelly AFB, Texas.*

HNUS. 1992a. *Final Draft Remedial Investigation Report for East Kelly, Site S-2.*

HNUS. 1992b. *Final Draft Site Investigation Report for East Kelly, Site S-7.*

HNUS. 1992c. *Final No Further Action Decision Document for East Kelly, Site S-2 .*

HNUS. 1992d. *Final No Further Action Decision Document for East Kelly, Site S-7.*

HNUS. 1993. *Final Remedial Investigation Report, Groundwater Zone 3, Kelly AFB, Texas*

McIntosh, Wayne E. and Robert C. Behm. 1967. *Geological and Foundation Investigation, Lackland Air Force Base, San Antonio, Texas*. Prepared for the U.S. Army Engineer District, Fort Worth.

Mitretek. *Physical and Chemical Characteristics of the Shallow Groundwater Zone and Sources of Groundwater Contamination in the Vicinity of Kelly Air Force Base, Texas. Volume I: Analysis and Recommendation, Volume 2: Aerial Photographs and Related Correspondence and Plates*.

Radian Corporation. 1982. *Installation Restoration Program, Phase I – Records Search, Kelly AFB, Texas*.

Radian Corporation. 1984. *Installation Restoration Program, Phase II, Stage 1 Field Evaluation, Final Report, Kelly AFB, Texas* .

Radian Corporation. 1988. *Installation Restoration Program, Phase II, Stage I Field Evaluation, Final Report, Kelly AFB, Texas, Final Data Report for the Period 1985 through September 1986*

Radian Corporation. 1986. *Phase II Confirmation/Quantification, Stage 2.*

SAIC. 1993. *Final Draft Focused Feasibility Study for Groundwater Remediation Site MP, Kelly AFB, Texas*

SAIC. 1996. *Final Feasibility Study for Zone 3 Groundwater, Kelly AFB, Texas*

SAIC. 1998a. *Informal Technical Information Report, Interim System Optimization and Evaluation, ITP Site MP, Kelly AFB, Texas*

SAIC. 1998b. *Informal Data Package, Remedial Investigation for Installation Restoration Program, Zones 2, 3, and 5, Sites MP/1500 Area/Tank 930, Kelly AFB, Texas*

SAIC. 1998c. *Informal Data Package, Remedial Investigation for Installation Restoration Program, Zones 2, 3, and 5, Sites MP/1500 Area/Tank 930, Kelly AFB, Texas*

SAIC. 1998d. *Informal Technical Information Report, Site MP Groundwater Recovery System Performance Evaluation, Kelly AFB, Texas*

SAIC. 2000. *Draft Final RCRA Facility Investigation Former Building 258 Solid Waste management Unit, Kelly AFB, Texas*

San Antonio River Authority (SARA). 2000. *East Kelly Air Force Base Chlorinated Plume Investigation in the Vicinity of the San Antonio River, Documentation Survey of the San Antonio River Aquatic Ecosystem from Alamo Street to Loop 410*.

Texas Natural Resource Conservation Commission. *RCRA Compliance Plan*. 1998

United States Geological Survey. 1999. Gain-Loss Study of Lower San Pedro Creek and the San Antonio River from Mitchell Street to Loop 410, San Antonio, Texas. May-September, 1999.

DEVELOPMENT OF A BASEWIDE GROUND-WATER FLOW MODEL AND ITS APPLICATION FOR SIMULATING ZONE 4 REMEDIATION OPTIONS AT KELLY AFB, TEXAS

DRAFT FINAL

Prepared for:

Air Force Center for Environmental Excellence
Brooks AFB, Texas

Project No. MBPB98-7903
Contract F41624-95-D-8005-0031
Delivery Order Number 031

May 2001

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

AFB	Air Force Base
AFBCA	Air Force Base Conversion Agency
AFCEE	Air Force Center for Environmental Excellence
BRA	Basewide Remedial Assessment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CMS	Corrective Measure Study
CMI	Corrective Measure Implementation
ERPIMS	Environmental Restoration Program Information Management System
DCE	Dichloroethylene
f_{oc}	fraction of organic carbon
fpd	feet per day
gpm	gallon per minute
gm/cm^3	gram per cubic centimeter
IRP	Installation Restoration Program
K	Hydraulic Conductivity
Kcal	Kilocalories
K_{oc}	Water/Organic Carbon Partition Coefficient
MCL	Maximum Contaminant Level
mg/L	milligrams per Liter
mg/kg	milligram per kilogram
mV	mili-Volts
ppb	parts per billion
PCE	Perchloroethylene
RCRA	Resource Conservation and Recovery Act

RFI	RCRA Facility Investigation
R_f	Retardation Factor
RI	Remediation Investigation
RMS	root-mean-square
SAIC	Science Applications International Corporation
SWMU	Solid Waste Management Unit
TCE	Trichloroethylene
TNRCC	Texas Natural Resource Conservation Commission
TOC	Total Organic Carbon
USEPA	U. S. Environmental Protection Agency
USGS	United States Geological Survey
USAF	United States Air Force
ug/L	micrograms per Liter
VC	Vinyl Chloride
VOC	Volatile Organic Compound
WPI	Waste Policy Institute

1.0 BACKGROUND

HydroGeoLogic is currently providing services, remediation man-hours and materials to perform continued ground-water flow and contaminant fate and transport modeling at Kelly Air Force Base (AFB), Texas, in support of the Air Force Base Conversion Agency Environmental Programs (AFBCA). HydroGeoLogic maintains a calibrated basewide ground-water flow model from which detailed transport models can be developed for specific areas of the base. These models have been successfully used to evaluate remediation alternatives and to support Corrective Measure Study (CMS) and Corrective Measure Implementation (CMI) activities at Kelly AFB.

1.1 BASEWIDE GROUND-WATER FLOW MODEL

Based on a comprehensive understanding of geology and hydrogeology conditions at Kelly AFB, HydroGeoLogic constructed and calibrated a basewide ground-water flow model for Kelly AFB in the spring of 1998. Because this basewide model was calibrated using hydrogeologic data collected up to December 1997, it is called the December-1997 model. Model simulations were performed using HydroGeoLogic's MODFLOW-SURFACT code. MODFLOW-SURFACT is a fully integrated ground-water flow and solute transport code based on the U. S. Geological Survey modular ground-water flow model, MODFLOW. Key aspects of the December-1997 basewide ground-water flow model are that:

- It is composed of four model layers that represent vertical heterogeneity in the alluvial aquifer;
- It simulates extraction wells, ground-water interaction with Leon Creek, aquifer recharge, and fluxes into or out of the model domain;
- It is calibrated to accurately represent slight changes in ground-water flow directions caused by seasonal fluctuations in water table elevations;
- It is constrained with hydraulic conductivity values that were estimated for all four-model layers at more than two thousand borelog locations; and
- It accurately reproduces the ground-water pathways inferred from plume concentration contour maps.

The basewide model calibration was performed using data fusion technology. This technology permits a wide range of hard and soft data to be used during the model calibration and supports efficient methods for model recalibration. The accuracy of the calibration model is directly related to the quality and quantity of the field data used for model calibration. Hence, the calibrated model is considered a work-in-progress. As more field data is collected or corrected, particularly in the area with scarce data points in the December-1997 basewide model, the updated basewide model can be improved on an as-needed basis.

The December-1997 model report was submitted to the Texas Natural Resource Conservation Commission (TNRCC) and US Environmental Protection Agency (USEPA) Region VI in March 1999 (HydroGeoLogic, 1999a). A meeting was held in July 1999 at TNRCC for HydroGeoLogic to present model construction and results to TNRCC and EPA. Since this submittal was voluntary, and was not a deliverable as part of a regulatory compliance program, neither regulatory agencies were required a formal review and approval.

1.2 REFINED FLOW AND TRANSPORT ZOOM MODELS

Aside from providing the capability to simulate the ground-water table at the regional scale, the basewide flow model provides a conceptual and numerical framework from which multiple zoom models can be developed to address local solute transport and remediation alternative issues at Kelly AFB. As implied by its name, a zoom model is developed by zooming into a portion of the basewide model and extracting all of the existing model inputs and field data measurements within the zoom model boundaries, then constructing a separate model by refining the numerical grid and inserting additional information. Zoom models can be utilized for specific areas such as a Solid Waste Management Unit (SWMU), a plume management area, a contaminant plume, or a remediation system.

In summer 1998, HydroGeoLogic developed a refined zoom model to evaluate whether horizontal wells are a viable alternative for replacing the recovery trenches proposed by Ch2M Hill for ground water capture at East Kelly. Using the December-1997 basewide model, the East Kelly zoom model was extracted and refined with a variable spaced numerical grid from 300 feet to 5 feet with the smallest grid space occurring in the vicinity where horizontal wells are to be placed. The East Kelly zoom model is composed of 84,568 grid cells on each of four model layers, for a total of 338,272 grid cells. Simulation results suggest that horizontal wells would be efficient for containing groundwater contamination on East Kelly. A letter report, Model Results for Assessing the Effectiveness of Horizontal Wells for Ground-Water Capture at East Kelly, was submitted to Kelly AFB on September 11, 1998. Ten horizontal wells were installed in East Kelly in 1999.

Extracted from the December-1997 basewide model, a refined flow and transport zoom model at Site S-4, Zone 3, was developed by HydroGeoLogic to support the Site S-4 CMS report in 1999. The zoom model was used to evaluate five remediation alternatives for the removal of the following chlorinated solvents: Tetrachloroethylene (PCE), Trichloroethylene (TCE), 1,2-Dichloroethylene (DCE), and Vinyl Chloride (VC). The remediation alternatives included extraction wells/trench, horizontal wells, natural biodegradation, enhanced in-situ biodegradation, and reactive walls. Detailed 30-year model simulations were provided for all four chlorinated solvents for each of the five remediation alternatives. Each simulation included adsorption, dispersion, and biodegradation. The first-order biodegradation rates for all four chlorinated solvents were developed based on site-specific data and were confirmed with model simulations. The Draft Final Report, Evaluation of Remediation Alternatives at Site S-4, Kelly AFB

Using a Ground-Water Flow and Transport Model, was delivered to Kelly AFB on August 31, 1999 (HydroGeoLogic, 1999b), and a Final Report was delivered to Kelly AFB on December 15, 2000 (HydroGeoLogic, 2000a).

In 1999, the December-1997 basewide model was expanded and calibrated with additional April 1999 data in support of the Zone 5 CMS report. Two refined zoom flow and transport models were developed for chlorinated solvent plumes designated as Plume A and Plume D-H-J at Zone 5. The numerical mesh of the two Zone 5 zoom models have spacing of 300-ft, 100-ft, and 50-ft, with the smallest grid space occurring in the vicinity of the proposed extraction well systems. Six extraction network systems were simulated for Plume A. One extraction system was simulated for each plume in the Plume D-H-J zoom model. All plume simulations were for 30-year periods. A detailed mass balance was constructed for each contaminant of PCE, TCE, DCE, and VC at every time steps in the transport model. This data was used to plot concentration plumes at 5-year intervals and to plot the decrease in maximum concentrations over time. A summary table provides the time of both on-base and off-base portions of plume to reach the Maximum Contaminant Levels (MCLs) for each extraction network. A Draft Final Report, Simulation of Extraction Systems for Zone 5 Plumes at Kelly AFB, Texas Using Transport Zoom Models Developed from the Basewide Ground-Water Flow Model, was submitted to Kelly AFB in January 2000 (HydroGeoLogic, 2000b).

This report consists of three main parts. Part 1 documents the expansion of the December-1997 basewide flow model. Part 2 describes the zoom flow model for Zone 4 off-base. Part 3 applies the zoom transport model for evaluation of remediation alternatives in support of the Zone 4 CMS report.

2.0 CONSTRUCTION AND CALIBRATION OF EXPANDED BASEWIDE FLOW MODEL

The December-1997 basewide ground-water flow model consists of a numerical grid of 300-foot x 300-foot grid cells in the horizontal plane and four equally spaced layers in the vertical. The model domain shown in Figure 2-1 includes all of Kelly AFB and extends off-base to the southeast. The calibration of the December-1997 basewide flow model was based primarily on data in the Environmental Restoration Program Information Management System (ERPIMS) up to December 1997. Approximately 2,000 borehole logs and 1200 water table measurements from four monthly sampling events were used as input for the model calibration. Results from the model calibration using Hydro-FACT were then entered in the code MODFLOW-SURFACT (HydroGeoLogic, 1998) to produce the calibrated model.

From 1998 to 1999 significant field data was accumulated outside of and within the boundaries of the December-1997 model domain. Figure 2-1 shows additional ground water table or soil boring data points that were not available for the December-1997 model calibration. Most of the new data is located in the area outside the December-1997 model domain. The quality of the calibration data set (such as water table, pumping rates, and recharge files) has been improved. The Zone 4 off-base plume extends east to the San Antonio River, beyond the boundaries of the December-1997 basewide model. These aforementioned considerations make it necessary to expand the December-1997 model domain, and thus produce a new basewide model based on updated data.

2.1 EXPANDED MODEL DOMAIN

Compared to the December-1997 basewide model, there is no major change of the expanded basewide flow model framework in term of its discretization scheme, vertical structure of its model layers, hydraulic boundary assignment, and interaction with the Leon Creek. Figure 2-2 shows the expanded basewide model domain, which has 109 rows, 173 columns and 4 layers, making a total of 75,428 grid cells. Significant expansion of the new model grid to the east resulted in a 120% increase of the active cell (from 4,594 to 10,133 per each model layer). The expanded model domain covers approximately 32.7 square miles. It includes all of Kelly AFB and extends northward past the State Highway 90, and southeastward toward Loop 410. The eastern boundary of the model consists of 8.2 miles of the San Antonio River (Figure 2-1).

Figure 2-3 shows the expanded model domain, USGS Digital Elevation Model (DEM) surface elevation contours, and geologic outcrops digitized from the Geologic Atlas of Texas San Antonio Sheet (Bureau of Economic Geology, 1983). Most of the area of the model domain is characterized with the fluviatile terrace deposits of gravel, sand, silt, and clay. To the southeast and southwest of the expanded model domain, the topographical high represents Wilcox and Midway groups of clay, silt, to mudstone of Tertiary Age. Compared to Quaternary fluviatile terrace deposits, the Tertiary soil formation is more resistant to weathering and erosion.

Figure 2-4 shows the total thickness of the model domain as calculated by subtracting the bottom elevation of the model's bottom layer from the top elevation of the model's upper layer. The model upper boundary was assigned as the minimum between the ground surface elevation and the elevation created by adding 7 feet to the April 1999 ground water table. The model bottom boundary represents the minimum between the top surface of the Navarro Clay and the elevation created by subtracting 5 feet from the April 1999 water table. Rationales for determination of model vertical layer structure are as follows:

- Include the entire saturated aquifer thickness above the Navarro Clay surface. In general, the lower two layers (layers 3 & 4) are associated with coarse-grained deposits (high K), and the upper two layers (layers 1 & 2) are associated with moderate to fine-grained deposits (low K);

- Minimize the vertical distortion of the numerical grid in order to reduce errors associated with calculating ground water flow;

- Maximize the spatial resolution used to represent the aquifer heterogeneity in the saturated aquifer so that preferential ground water pathways could be represented in the model; and

- Include the upper several feet of the Navarro Clay in areas where it penetrates or nearly penetrates the water table surface so that lateral hydraulic boundaries can be properly represented.

2.2 CALIBRATION DATA

The expanded basewide model was developed using an extension of the April 1999 water table data set, additional borelog information, representative pumpage rates for each remediation system, and revised recharge rates for each zone based on examination of aerial photography.

2.2.1 Water Table Measurements

A composite data set for March 1996 and December 1997 water table measurements was used as the primary calibration targets for the December-1997 basewide model. There are 343 data points (average of March 1996 and December 1997 water table) in that composite data set. A more extensive sampling event of 1999 Basewide Remediation Assessment (BRA) was conducted in March-April 1999 (referred to the April-1999 in this report). Ground-water elevation data of nearly one thousand wells were obtained from ERPIMS database for this sampling event.

In addition, Science Applications International Corporation (SAIC) provided HydroGeoLogic with a spreadsheet for water table measurement conducted in April 1999 as part of Site S-4 CMS activity. Among the SAIC data, 26 wells were also sampled in the BRA event. There were 8 new SAIC wells, from which water table data was added into the basewide April 1999 data set.

As part of additional phase RFI, CH2M Hill conducted a Zone 4 off-base screening study in March-April 1999 using 83 flight auger probes. 73 push holes with north, east, and depth to ground water data were selected to augment the April 1999 water table dataset.

Figure 2-5 shows locations of data from the 1999 BRA, SAIC, and Ch2M Hill push holes and contours of ground water table developed by kriging all April 1999 data measurements. Kriging is a geostatistical method for data interpolation and contouring, which takes into consideration the spatial variance, location, and sample distribution in data. The kriging method is particularly useful in heterogeneous porous media when used to contour hydraulic heads. As shown in Figure 2-5, the highest hydraulic heads occur in the northwest corner of the Kelly AFB, which is located on the center of the Navarro Ridge. From this northwest region, ground water flows to the east, southeast, south, and southwest to Leon Creek. Ground water also flows to the northeast from this mounding area. The ground water flow direction and gradient at the expanded basewide scale is similar to DEM contours observed in Figure 2-3, indicating the ground surface elevation is the major control of the regional ground water flow.

2.2.2 Borelog Data and Hydraulic Conductivity Calculation

Hydraulic conductivity values estimated from lithology description of 2,166 borelogs were used as the secondary calibration targets for the December-1997 basewide model. The following new borelogs were added to help calibrate the expanded basewide model:

- 29 borelogs associated with Site S-4 CMS work;
- 80 borelogs associated with Zone 5 RCRA Facility Investigation (RFI) and CMS activities;
- 59 borelogs and 73 push hole description associated with Zone 4 off-base investigation; and
- 59 borelogs associated with installation of vertical and horizontal wells at Site MP and East Kelly.

In addition, an extensive search was conducted in Spring 2000 for potential sites located in the east Kelly off-base area under various state programs, which included the TNRCC Leaking Petroleum Storage Tanks, Volunteer Cleanup Program, and engineering designs from Department of Transportation. The search had generated 62 borelogs. For the borelog information obtained from other sources, estimations of easting, northing, and ground elevation were made based on overlaying of street location with a DEM surface contour map. The same lithologic group number of soil used in ERPIMS was assigned to the corresponding soil description in these additional borelogs.

Figure 2-6 shows the location of approximately 2,500 borelogs contained in the expanded basewide model domain. Among these borelogs, approximately 70% of the borings ended at the Navarro Clay. Figure 2-7 is top elevation contour map of Navarro Clay based on the elevation of top of Navarro Clay, or bottom of Navarro Transition for borings without Navarro Clay, or the bottom of gravel for push holes which show only gravel intervals. It is apparent there is a ridge like feature to the north center of Kelly AFB, and a Navarro Escarpment to the southwest. Ground-water flow directions depicted on Figure 2-5 closely match the surface elevation of the Navarro Clay. The generated Navarro surface elevation was used to develop the bottom elevation for the expanded basewide model.

The lithologic units documented in the borelogs can be used to help constrain the model calibration. Each lithologic type needs to be assigned a representative hydraulic conductivity value. As part of the development of the December-1997 basewide ground-water model, a detailed methodology was used for calculating an average hydraulic conductivity value for each lithologic unit using results from slug and pumping tests. This methodology involved a regression analysis that used the geological log data and transmissivity results from over 300 well locations. The regression analysis was performed to select the set of hydraulic conductivity (K) values for the major lithologic units that would minimize the difference between the predicted transmissivity as calculated from the borelogs and the measured transmissivity values (from pumping and slug tests). The specific details associated with the regression analysis are provided in the December-1997 basewide model report (HydroGeoLogic, 1999a).

The estimated mean K for each lithologic unit is shown in Table 2-1. Except for the clay lithologic unit, the magnitude of the hydraulic conductivity values is within the ranges typically shown in textbooks. There is a trend of higher hydraulic conductivity values corresponding with increasing the mean grain size. The 21 ft/day hydraulic conductivity assigned to the clay lithologic unit is attributed to the presumption that the clay classification includes a wide range of deposit types that span from 1-2 foot layers of a highly plastic clayey deposit to 3-5 foot zones of clayey deposits of sandy materials. As a result, the clay lithologic unit is considered to represent a deposit frequently characterized by silts and sands.

Because of the heterogeneous nature of the aquifer deposits, a confidence level equivalent to about factor of 5 is associated with each of the mean K values. For instance, a mean K for the Clayey Gravel is about 100 ft/day, so the estimated range of the Clayey Gravel is about 20 to 500 feet/day. Although this range may seem large, these ranges are very similar to those that are derived for each lithologic unit based strictly on the field data. All K values in the model were bounded by the minimum and maximum values of 0.1 and 1,400 ft/day. Using the information in Table 2-1 and an average hydraulic conductivity of 0.1 ft/day for the upper portions of the Navarro Clay in the model domain, the lithologic profiles were transformed into continuous profiles of hydraulic conductivity values at approximately 2,500 borelog locations for the four model layers.

Because of the similar K values associated with three of the lithologic units (Clay with Sand Lenses, Silt, and Sand) these units can be considered, for all practical purposes, as representing the moderate to low-K deposits at Kelly AFB. The Clayey Gravel and

Gravel Units therefore represent the moderate to high-K deposits at Kelly AFB, respectively.

Table 2-1
Estimated Mean Hydraulic Conductivity (K) Values for the Major Lithologic Units Based on Results from the Regression Analysis for Basewide Simulations

Major Lithologic Units Description	Estimated Mean K (ft/day) Used in Basewide Model
Fill	62
Clay with Sand Lenses	21
Silt	20
Sand	33
Clayey Gravel	95
Gravel	349

2.2.3 Extraction Well Pumping Rates

Extraction rates for remediation systems were entered as a sink/source item for model calibration. Currently, there is a flow meter for each extraction well associated with a remediation system. In addition, there is a flow meter that measures the cumulative pumping from all of the extraction wells in the remediation system. These flow meters are read at approximately monthly intervals. Pumping rates are calculated by dividing the total flow measured by the meters and by the number of days between measurements.

Waste Policy Institute (WPI) provided HydroGeoLogic with a spreadsheet that contains monthly total discharge readings for each extraction well at all remediation sites. For each well, monthly flow rates were calculated, tabulated, and averaged. In most systems, there existed data discrepancies such as backwards flow meter reading, completely new flow meter numbers suggesting change/resetting of flow meters, etc. These problems were more frequent with older data. Much of the well data had at least one or more monthly values that were much greater than the average values. Although some of the higher monthly pumping rates may have represented actual flow rates, those monthly values that exceeded the average value by more than a factor of ten were likely caused by errors associated with the measurement, and were considered outliers.

Because of potential problems with outliers and missing data, HydroGeoLogic reviewed the pumping rates for March, April, and May of 1999 in order to determine a representative pumping rate for the April-1999 basewide model. A table provides total pumping rates in gallons per minute (gpm) for each remediation system shown in Figure 2-8.

2.2.4 Recharge Rates

Prior to model calibration, the model domain was divided into regions of expected similar recharge. This division is based on a wide-range of factors including land usage, topography, depth to ground water and soil types. Most of the divisions used for recharge in the December-1997 model were used in the expanded model. The recharge divisions in the expanded model are based on a more through evaluation of the field data. Some of the factors used to delineate the recharge divisions are as follows:

- Examined vegetation coverage and land use pattern in aerial photography;
- Developed recharge distribution data in the expanded model cells by extrapolating from the existing recharge zones due to similarities of land use patterns;
- Evaluated a digitized San Antonio Geologic Map for separated zones of recharge with different subsurface geologic deposits; and
- Calculated a recharge rate of 5.7 inch/year for a golf course near Leon Creek based on the meter reading of irrigation system in April 1999 divided by total area of the golf course.

2.2.5 Interaction between Leon Creek and the Ground Water

Leon Creek is an extensive urban stream, which is roughly 45 miles long and drains over 200 square miles of land in western Bexar County. There is roughly a 3.5-mile segment of this creek adjacent to Kelly AFB. Historically, this segment has had little water flow (< 10 cubic feet/second (cfs)) during any given year, but during storm events it has had stream flows exceeding 1,000 cfs.

Since 1994, the total flow in Leon Creek has been measured at five different locations at eight times. The total flow measurements are summarized in Table 2-3. CH2M Hill (1996) provides a detailed explanation of the measurement methods. The calculated difference in total flow at these five locations produces a net gain/loss in creek flow for the four segments shown in Figure 2-9. The calculated net flow gain/loss for these four locations are in Table 2-3. The average stream gain/loss for segments 1 to 4 are 0.15, 0.88, 1.3, and 0.06 cfs, respectively. The average stream gain/loss for each four segments ranges from -0.97 cfs to 5.06 cfs and with a net of 2.4 cfs. These analyses indicate that the creek is primarily gaining water from ground water as it passes through Kelly AFB. At the southern section of Kelly AFB, Leon Creek may lose water to the ground-water system (CH2M Hill, 1996).

Large temporal and spatial variability exists for all of the creek segments. Some of the temporal variability may be caused by changes in the pumping rates at nearby extraction wells (see Figure 2-8). The average stream flow per segment is 0.59 cfs whereas the standard deviation of the eight averaged measurements is 0.82 cfs. An important characteristic of Leon Creek is that it has been extensively modified by manmade features (dams, culverts) and receives most of its water from outfalls, which include at least 20 effluent and stormwater discharge pipes and six seeps.

Table 2-2
Measurements of Total Flow in Leon Creek at Locations within the Boundaries of Kelly AFB

Event	Measurement Date(s)	LEON CREEK Segment	UPPER SEGMENT Stream Flow	SEGMENT GAIN/LOSS (-) (cfs)
1	March 18-19, 1994	1	2.43	-0.94
		2	1.49	1.82
		3	3.31	2.27
		4	5.58	-0.75
		1-4		2.4
2	May 19-21, 1994	1	7.54	0.45
		2	8.11	1.76
		3	9.92	1.35
		4	12.18	1.17
		1-4		4.73
3	August 22, 1994	1	0.31	0.18
		2	0.49	-0.09
		3	0.34	1.29
		4	2.39	-0.36
		1-4		1.02
4	October 24, 1994	1	5.08	0.38
		2	5.31	1.93
		3	6.15	2.01
		4	8.2	0.74
		1-4		5.06
5	June 13, 1995	1	3.82	0.38
		2	4.21	1.93
		3	6.18	2.01
		4	8.45	0.74
		1-4		5.06
6	November 14, 1995	1	0.21	0.33
		2	0.54	-0.26
		3	0.29	0.57
		4	1.01	1.12
		1-4		1.76
7	June 29, 1996	1	0.19	-0.01
		2	0.18	0.13
		3	0.33	0.58
		4	0.98	-0.6
		1-4		0.1
8	January 25, 1997	1	0.73	0.45
		2	1.18	-0.17
		3	1.01	0.36
		4	1.52	-1.61
		1-4		-0.97
Average for Measurements 1-8		1	2.54	0.15
		2	2.69	0.88
		3	3.44	1.31
		4	5.04	0.06
		Net		2.40

Available data suggests that most of the variations in the creek flow are caused by variations in the flows from the outfalls and not by variations in the interaction between the surface water and ground water. For instance, in Segment 4, most of the creek discharge can be attributed to the base's Environmental Process Control Facility. A benefit of the dams and culverts in Leon Creek is that the water elevation along Leon Creek remains relatively constant during various base flow conditions.

2.2.6 San Antonio River Water Budget Study

From May 1999 to October 1999, the U. S. Geological Survey (USGS) conducted a gain-loss study to quantify ground water inflow to the San Antonio River. Figure 2-10 shows locations of streamflow measurements and designated river sub-reaches. Sub-reach A is San Pedro Creek from Furnish Avenue to the confluence with the San Antonio River; Sub-reaches B through F are respectively the San Antonio River from Mitchell Street to Theo Avenue, from Theo Avenue to Roosevelt Avenue, from Roosevelt Avenue to Padre Park Dam, from Padre Park Dam to Ashley Road, and from Ashley Road to Loop 410. All selected sub-reaches are corresponding to the east boundary of the expanded basewide model.

A table in Figure 2-10 summarizes the estimated ground water inflows to the river sub-reaches. Positive values indicate ground water inflow to sub-reach (loss of the aquifer). Negative values indicate streamflow loss to ground water (gain of the aquifer). Four of the six sub-reaches measured during the study exhibited shallow ground water inflow to the San Antonio River. Only lower San Pedro Creek and the San Antonio River from Padre Park Dam to Ashley Road did not. During the five-measurement survey, the estimated ground water inflow from Mitchell Street to Padre Park Dam averaged 4.5 cfs. The estimated ground water inflow from Ashley Road to Loop 410 (Sub-reach F) averaged 1.0 cfs. Sub-reach F includes the Six-Mile Creek tributary, which has a small baseflow (about 0.4 cfs) during each of the measurement surveys.

2.3 CALIBRATION RESULTS

Model calibration is a process of refining the model representation of the hydrogeological framework, aquifer hydraulic properties, and boundary conditions until a desired correspondence is achieved between the model simulation and measured field data. The expanded basewide model calibration primarily focused on reproducing April 1999 hydraulic head measurements and estimated hydraulic conductivity values from over 2,500 borehole logs. Where multiple measurements were associated with the same grid cell, the average value of the multiple measurements was used as the calibration target. After grid assignment, there were more than six hundred head targets and seven thousands hydraulic conductivity targets for calibrations. The primary model parameter adjusted during model calibration was the hydraulic conductivity field.

An inverse modeling code (Hydro-FACT Version 2.1) based on data fusion technology was used for model calibration. Input to Hydro-FACT included measurements of hydraulic head and estimates of hydraulic conductivity. All of these measurements included both targeted values and estimates of their uncertainties. Benefits of using an inverse modeling code for calibration are described in the basewide flow modeling report (HydroGeoLogic, 1999a).

2.3.1 Hydraulic Head

Figure 2-11 shows calibrated hydraulic heads represented by model layers 2 and 4 of the April-1999 basewide model. While they show very similar patterns, Model Layer 4 contains the most transmissive aquifer materials. In order to help evaluate the accuracy of the calibrated model, Figure 2-12 shows the differences between the measured and predicted hydraulic head values for all four model layers. These differences are frequently referred to as a residual.

A useful statistic that represents an average deviation is the root-mean-square (RMS). A RMS for a residual is calculated by dividing the square root of the sum of the square values of residuals by the number of values. For approximately 650 head points shown in Figure 2-11, the RMS is 2.1 feet. This RMS value is about 2% of range (590 ft to 690 ft) in hydraulic head values across the model domain with the water table measurement coverage. Typically, a model result with RMS less than 5% of the head drop across a domain is acceptable.

Another useful statistic is the average bias. The average bias of 0.37 ft was calculated for the residuals by dividing the sum of residuals by the number of residuals. Such a small value indicates there is very little bias associated with the calibrated model. Since the residuals in Figure 2-12 are calculated by subtracting the predicted from the measured value, the positive sign indicates that the model has a slight tendency to underpredict the hydraulic head measurement.

2.3.2 Hydraulic Conductivity

Figure 2-13 shows the hydraulic conductivity field of Layers 3 and 4, respectively, generated by model calibration. These two layers represent approximately 85% of the model's saturated thickness. The continuity of lenticular-like low-K and high-K deposits is apparent across most of the model domain. Zones of high-K (>1000 ft/day) deposits appear to be continuous at distances greater than 2,000 feet. Figure 2-14 presents calculated transmissivity field for saturated portion of the calibrated model.

The differences between the targeted K values (which were derived from the borelog descriptions), the mean K values for each lithologic unit, and the K values in the calibrated model comprise the set of K residuals. Figure 2-15 shows the residuals in natural log (Ln) scale for approximately 7,000 hydraulic conductivity calibration targets by layers. The RMS for Ln K match is 1.81. The distribution of over and under estimations is relatively uniform.

2.3.3 Recharge

Figure 2-16 shows the recharge distribution from the expanded basewide model. Factors that affect the spatial variability of recharge include land cover and usage, recharge by sprinkler systems or leaking underground pipes, and depth to water table and aquifer deposits. The average recharge across the model domain is 2.8 inches/year. The range in recharge varies from 0.6 inches/year to 4.0 inches/year. The lowest recharge values are associated with the Navarro Escarpment in the southwest and the areas of East Kelly that contain a high percentage of paved surfaces.

The average recharge rate of 2.8 inches/year is consistent with previous results from field and modeling studies. Basewide recharge rates of 1 to 5 inches/year have been derived from a water budget analysis of Leon Creek (CH2M Hill, 1997). The December 1997 basewide model has an average recharge rate of 2.0 inches/year and has a recharge rate of approximately 3.5 inches/yr for the central portion of Kelly AFB.

2.3.4 Water Budget

Table 2-3 summarizes the ground-water fluxes into and out of the basewide model domain. Positive values represent gains to the aquifer while negative numbers represent losses to the aquifer. The positive recharge flux represents the amount that reaches the water table. The negative recharge represents the amount of water that is not admitted into the model or is discharged from the model because the ground water level has reached the ground surface. The well flux represents the total pumping of all 83 wells in the model domain. The river flux represents the gains and losses along Leon Creek and the San Antonio River. The model boundary fluxes include the amount of ground-water that is entering and leaving the sides of the model through the model's boundary cells. The model was solved for steady-state flow with a mass balance error of 0.02 %.

Table 2-3
Ground-Water Fluxes (ft^3/day) Calculated by the Basewide Model

Basewide	Recharge	River	Well	Drain	Model Boundary	Total Flux
In	515870	218860	0	0	297920	1032650
Out	-52800	-832620	-12496	-792	-133690	-1032398
Net	463070	-613760	-12496	-792	164230	252
Mass Balance						0.02%

2.3.5 Flow Paths

The flow model calibration was checked to ensure that ground-water flow pathways are consistent with the movement of contaminant plume. This check was performed by superimposing predicted flow pathlines over the outline of the contaminant plumes. This approach is good for determining if the flow pathlines have a general match to ground-water pathlines inferred from the plume configurations. When comparing the two sets of pathlines, one needs to consider all of the possible explanations that could cause differences. These reasons include historical changes in flow caused by remediation systems, plume shrinkage due to biodegradation, and the effects of three-dimensional flow.

Flow paths are generated from the model's velocity field via particle tracking. Particle tracking involves moving particles through the three-dimensional model domain based on the ground-water velocity vectors determined for each model cell. Figure 2-17 illustrates the particle tracks superimposed on top of the TCE contours based on 1999 data. The particle tracks map the advective migration of ground water with time marked at a five-year interval on the pathlines. The particle tracking results are consistent with the ground-water flow directions that can be inferred from the plume configuration. This agreement, along with the excellent mass balance and matches to the hydraulic head values indicates that the expanded basewide model was sufficiently calibrated to support contaminant transport simulation.

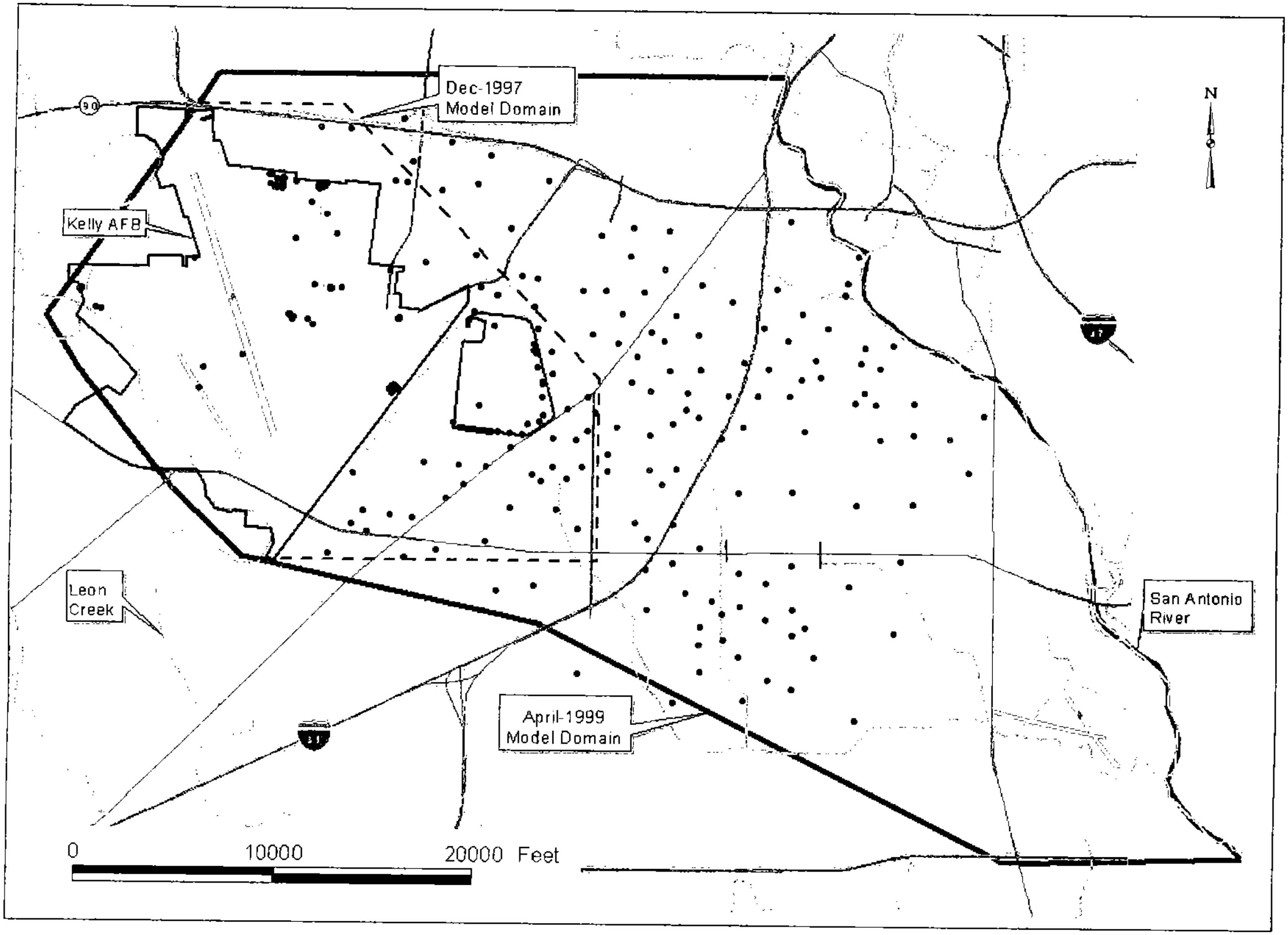


Figure 2-1. The December-1997 and Expanded April-1999 Model Domains and Locations of Additional Water Table or Borelog Data Points

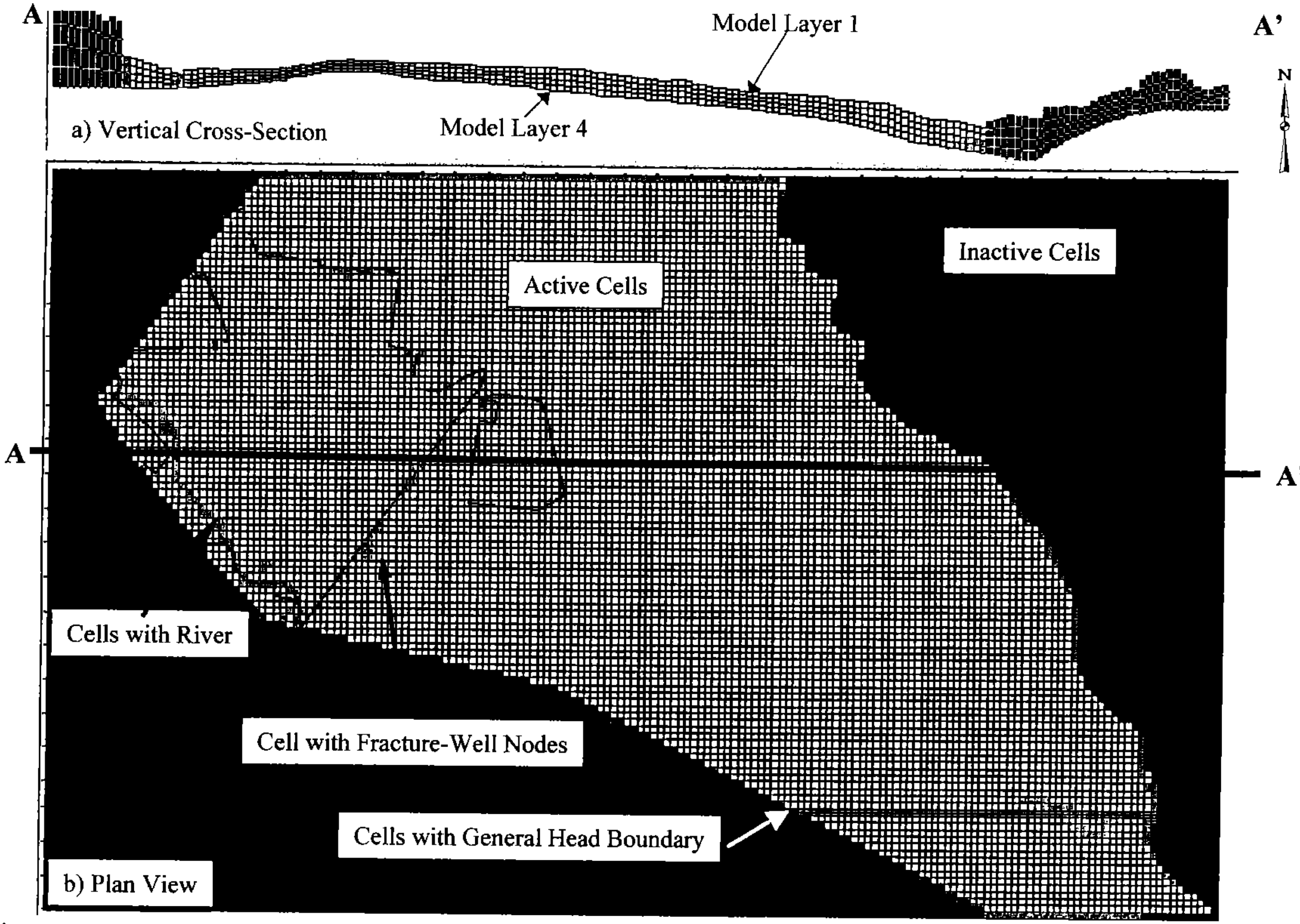


Figure 2-2 The Expanded Basewide Model Domain and Grid Cells: a) Vertical Cross-Section, and b) Plan View

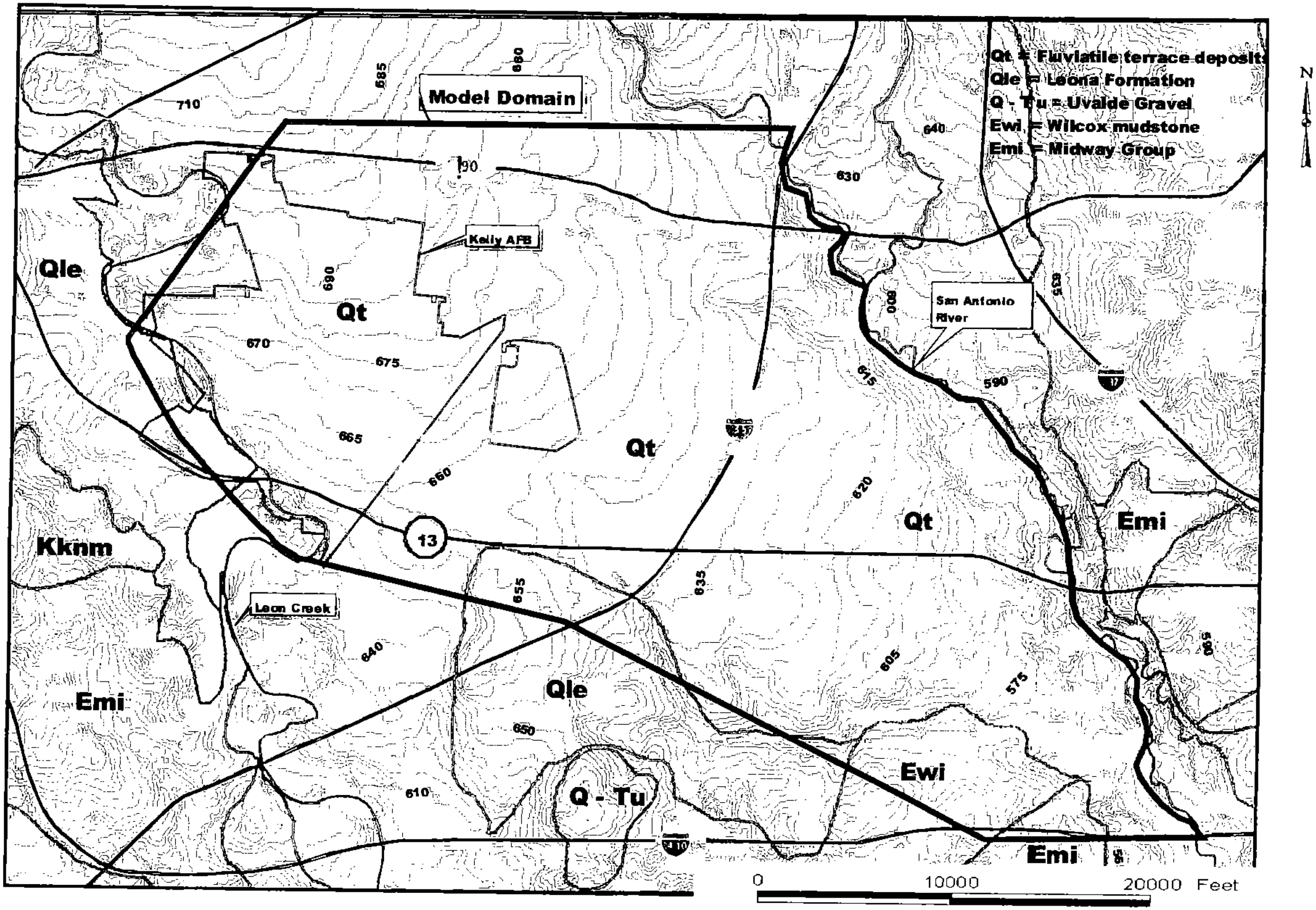


Figure 2-3 Regional Geologic Formation Overlaid with DEM Surface Contours (in feet above National Geodetic Vertical Datum).

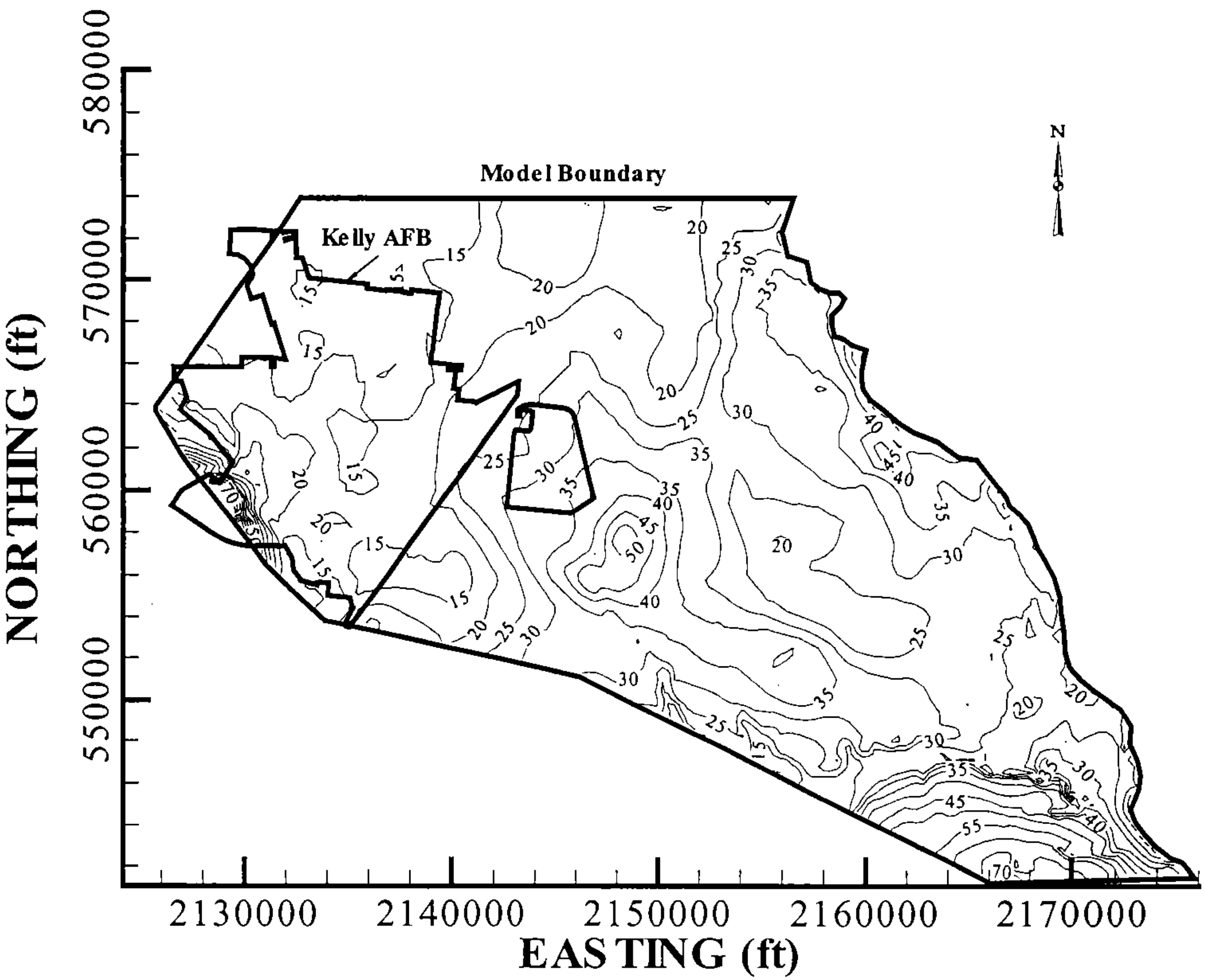


Figure 2-4 Contour Map of Model Thickness (ft)

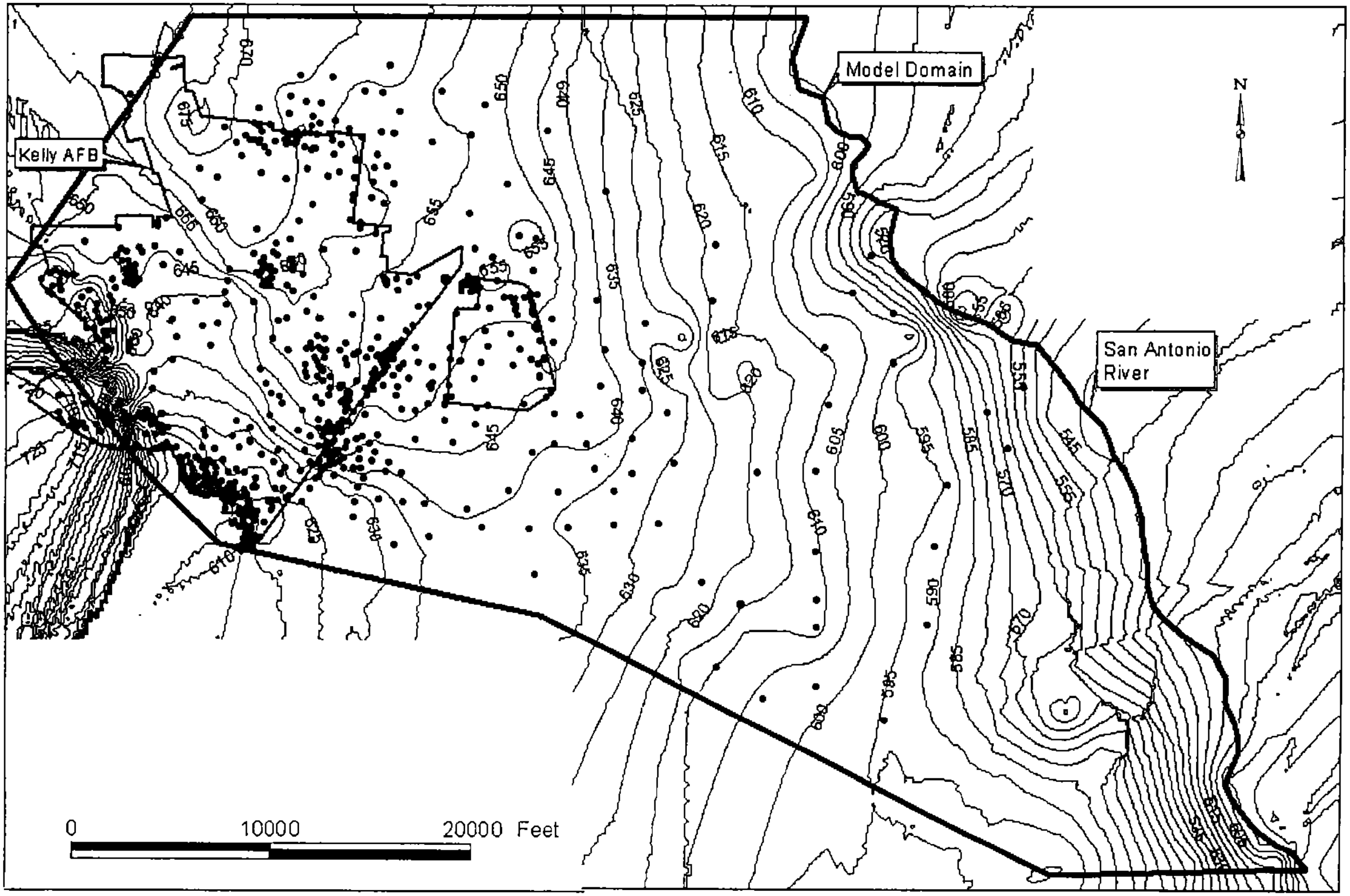


Figure 2-5 Locations of Hydraulic Head Measurements and Generated April 1999 Water Table Contour (in feet) for Expanded Basewide Model Calibration

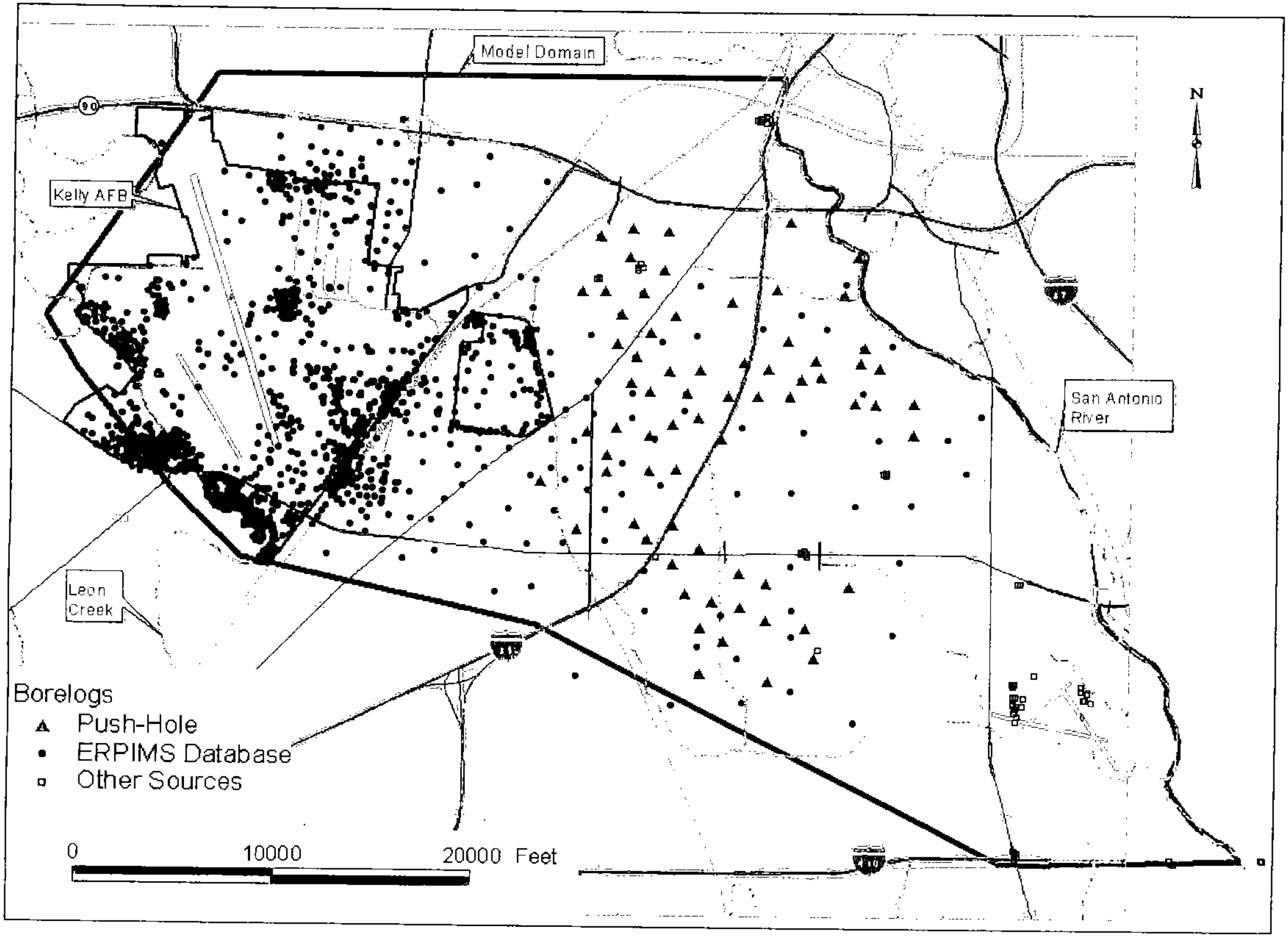


Figure 2-6 Locations of Borelogs for Expanded Basewide Model Calibration

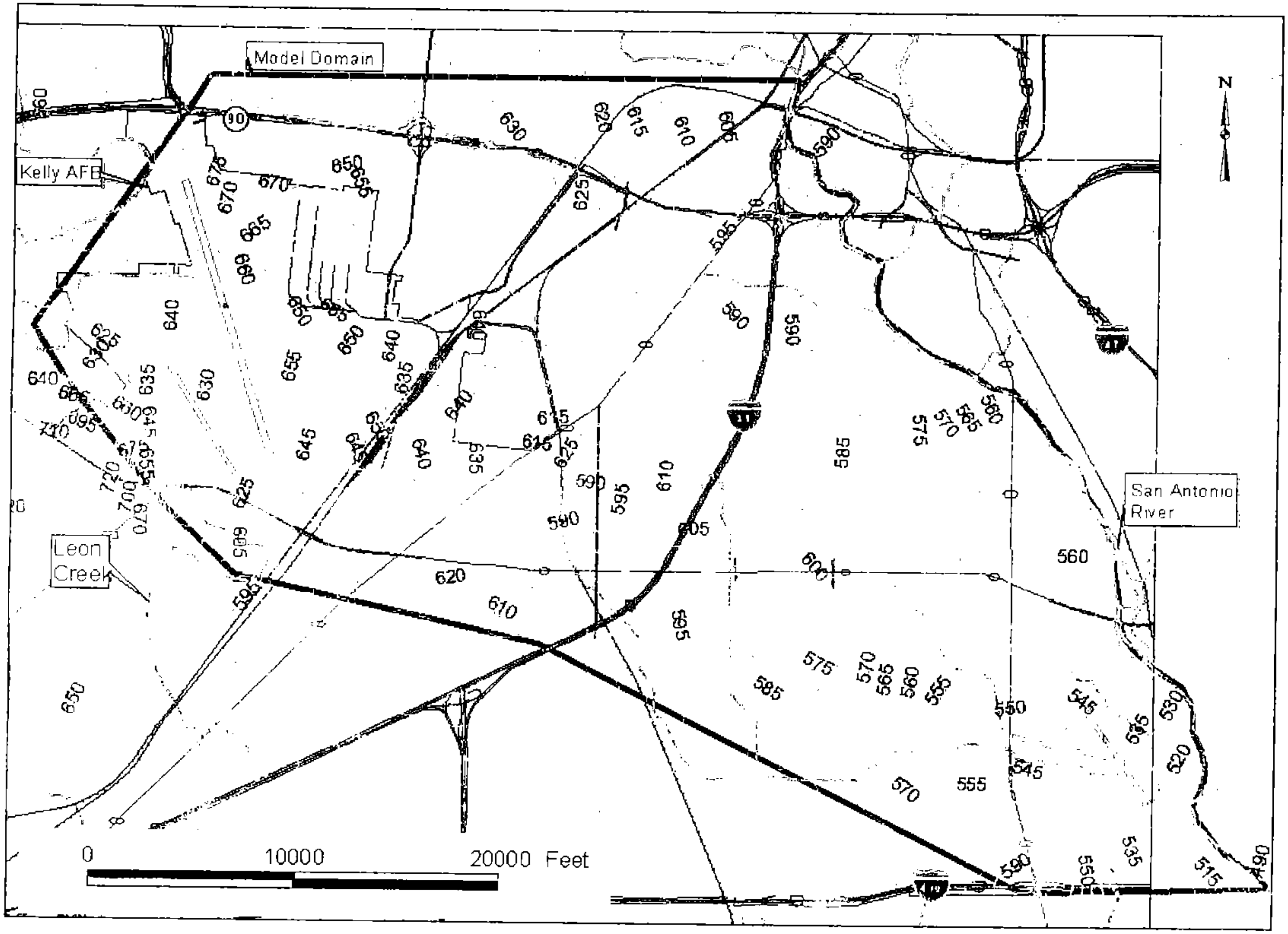
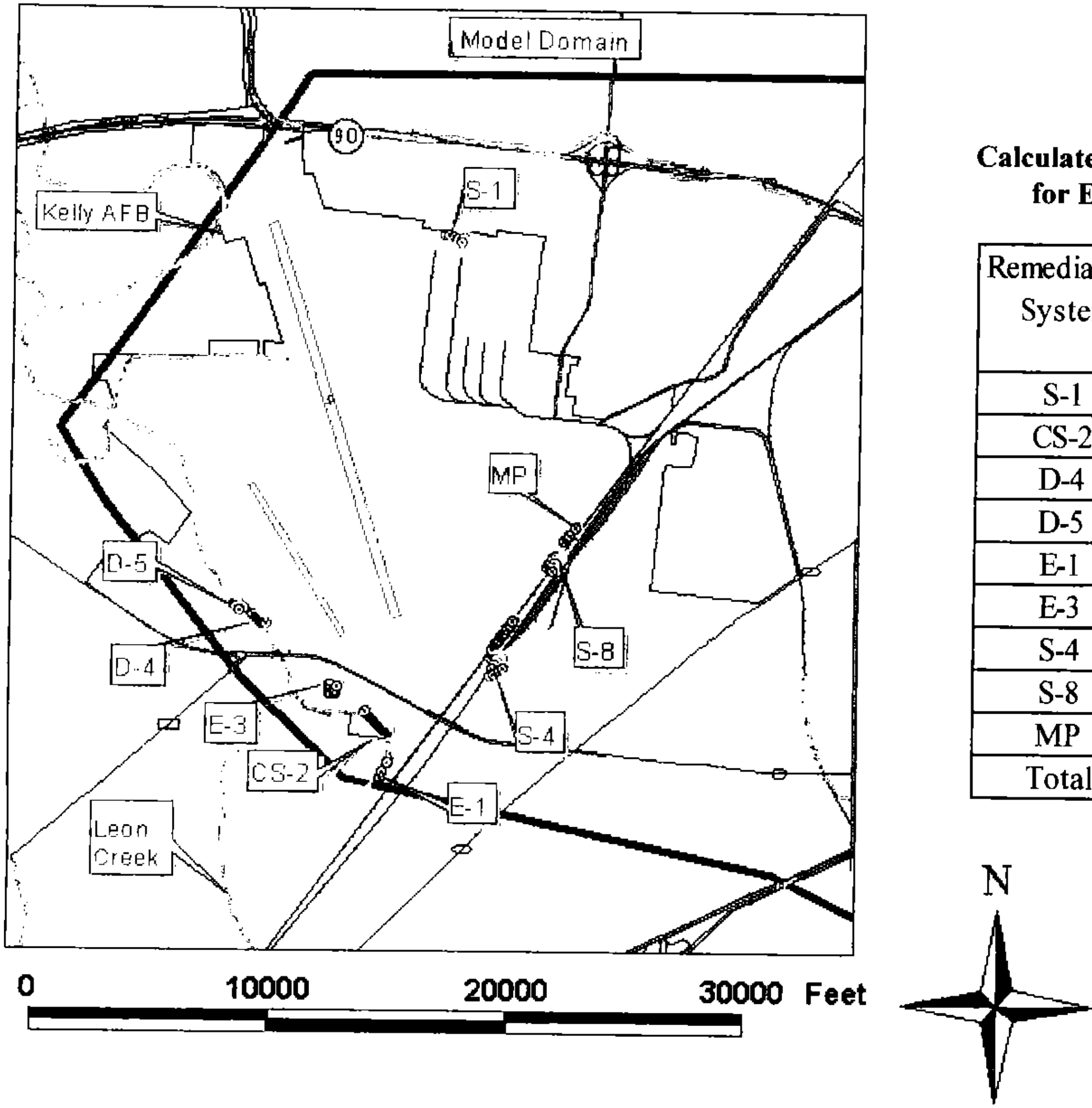


Figure 2-7 Generated Elevation Contours of Navarro Clay for Expanded Basewide Model Calibration
Elevations are in feet above National Geodetic Vertical Datum (NGVD).



Calculated April 1999 Pumping Rates for Each Remediation System

Remediation System	Numbers of Wells	Pumping Rates (gpm)
S-1	6	1
CS-2	12	10
D-4	14	24
D-5	3	2
E-1	3	5
E-3	6	7
S-4	24	7
S-8	12	8
MP	3	53
Total	83	117

Figure 2-8 Locations of Remediation Systems and Representative April 1999 Pumping Rates

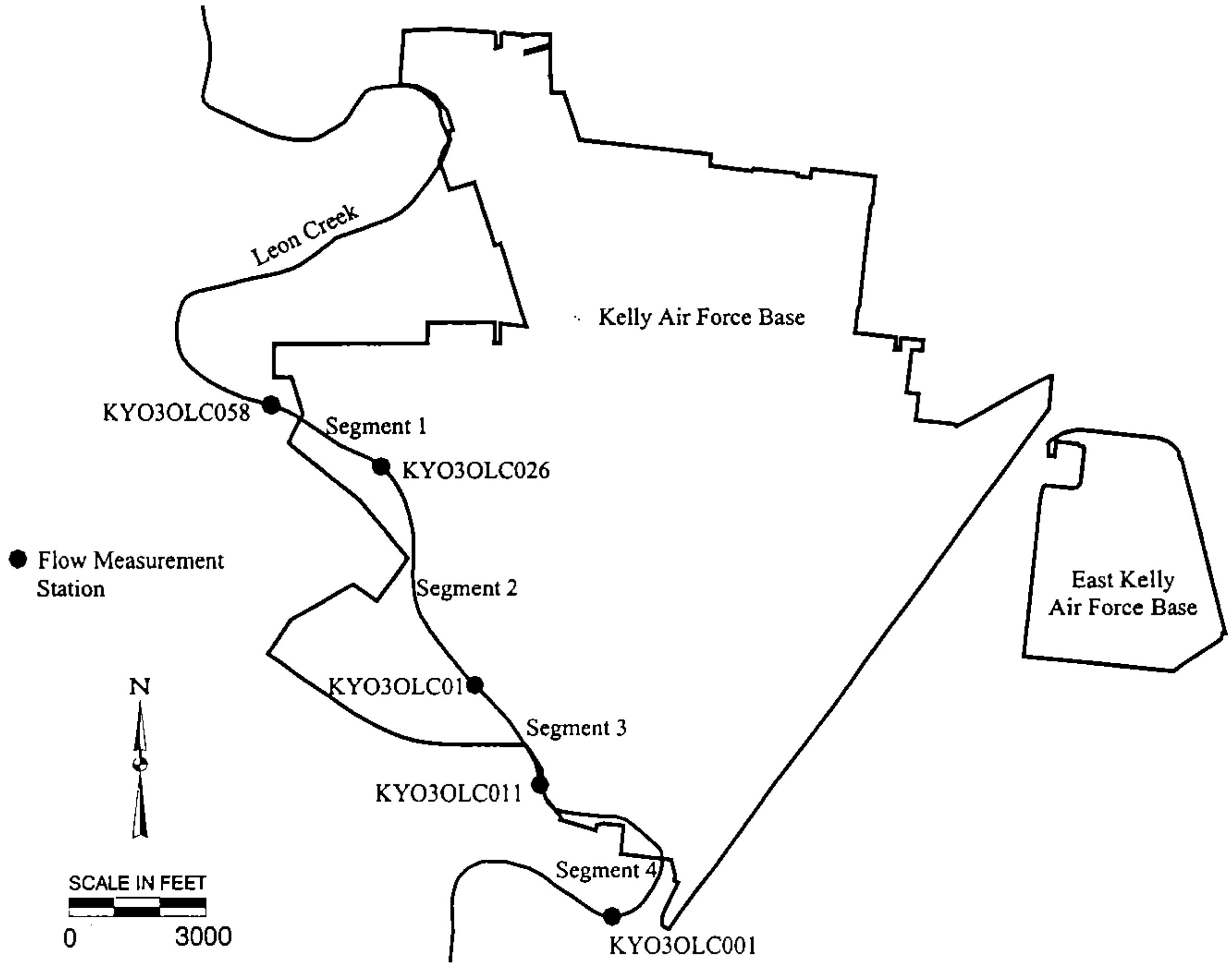
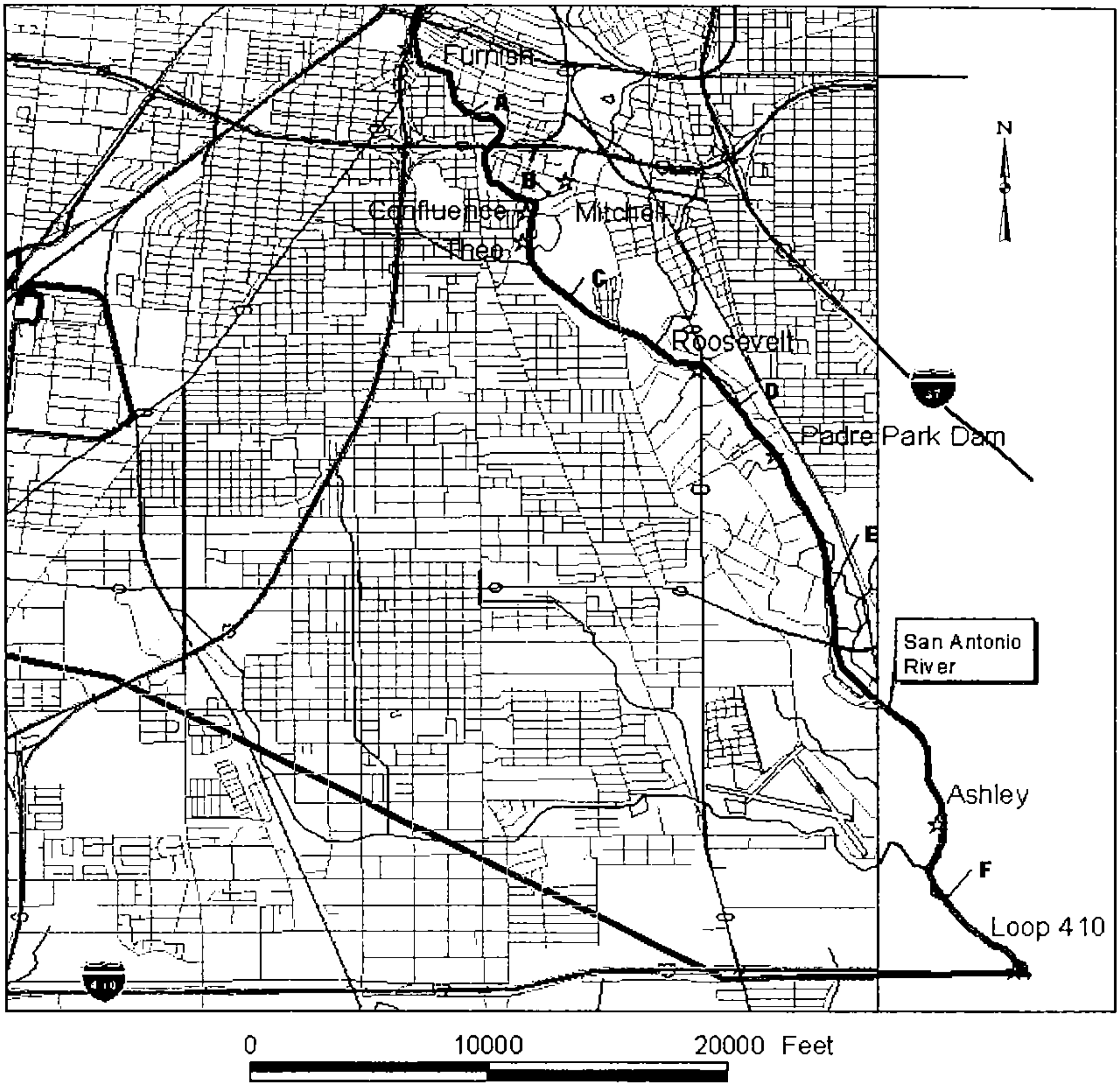


Figure 2-9 Locations of the Four Flow Measurements for Water Budget Surveys Performed at Leon Creek



Sub-Reach	26-May	8-Jun	27-Jul	27-Sep	27-Oct	Average
A	--	--	0.4	-0.3	-1.3	-0.4
B	--	--	2.2	0.9	-0.3	0.9
C	*	1.2	0.3	0.8	2.3	1.2
D	*	0.6	3.8	0.4	0.3	1.3
E	0.3	-1.5	-2.6	-0.4	-1.6	-1.2
F	0.1	0.1	0.7	1.4	2.6	1.0

Figure 2-10 Locations of 1999 USGS Streamflow Measurements and Sub-Reaches; All values in cubic feet per second; -- indicates not measured

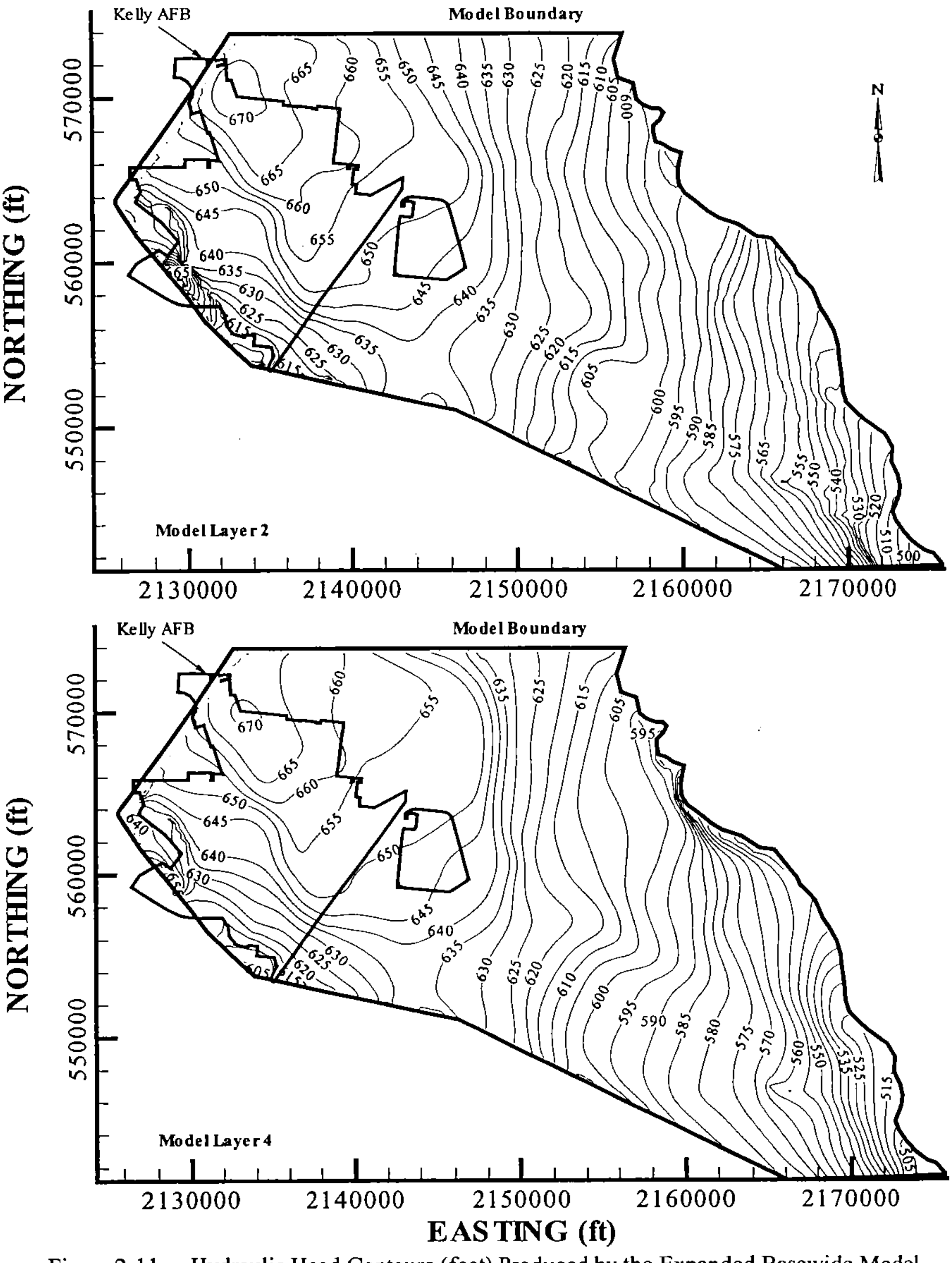


Figure 2-11 Hydraulic Head Contours (feet) Produced by the Expanded Basewide Model Calibration

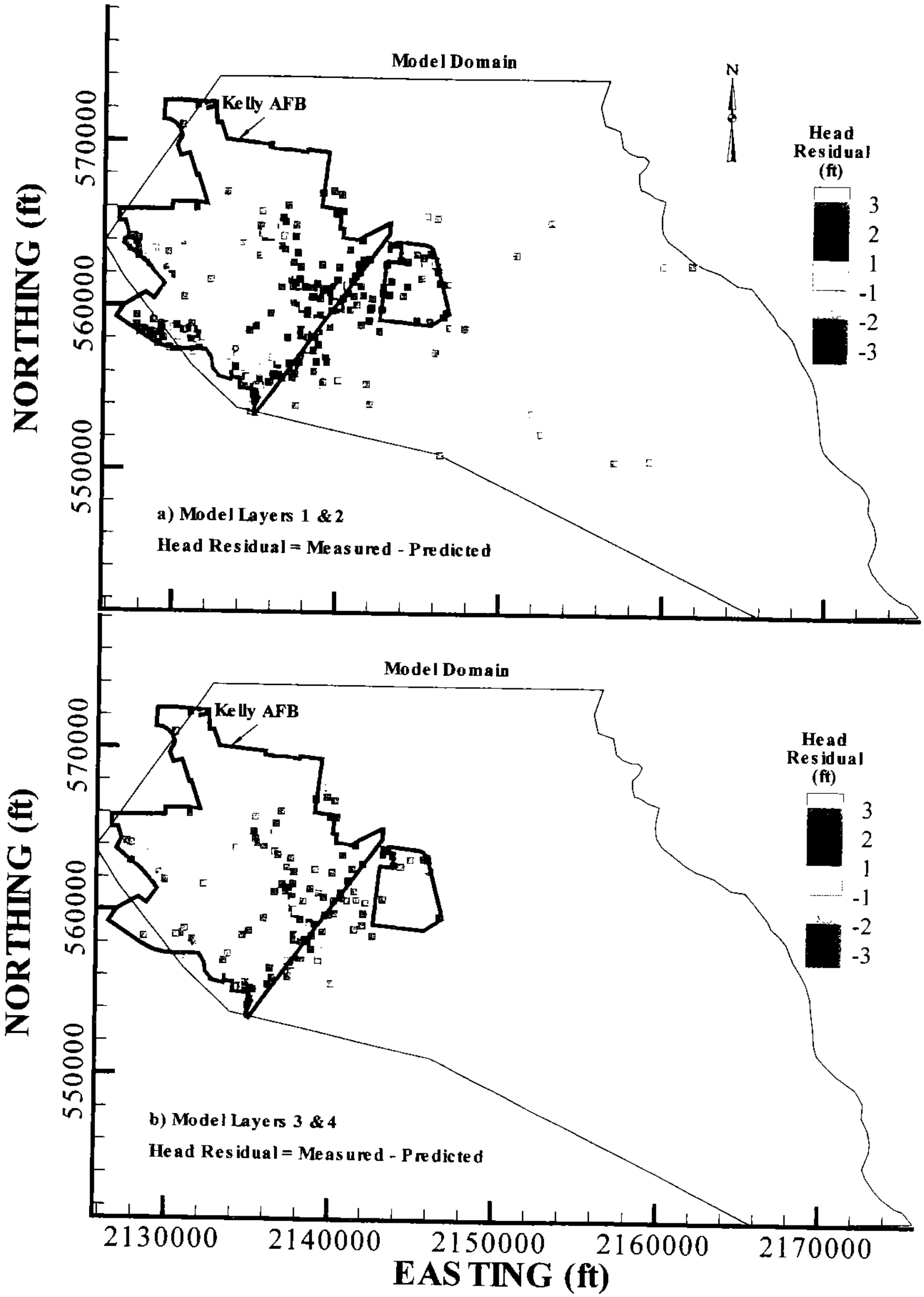


Figure 2-12 Hydraulic Head Residuals – Head Differences between Measured and Model Predicted

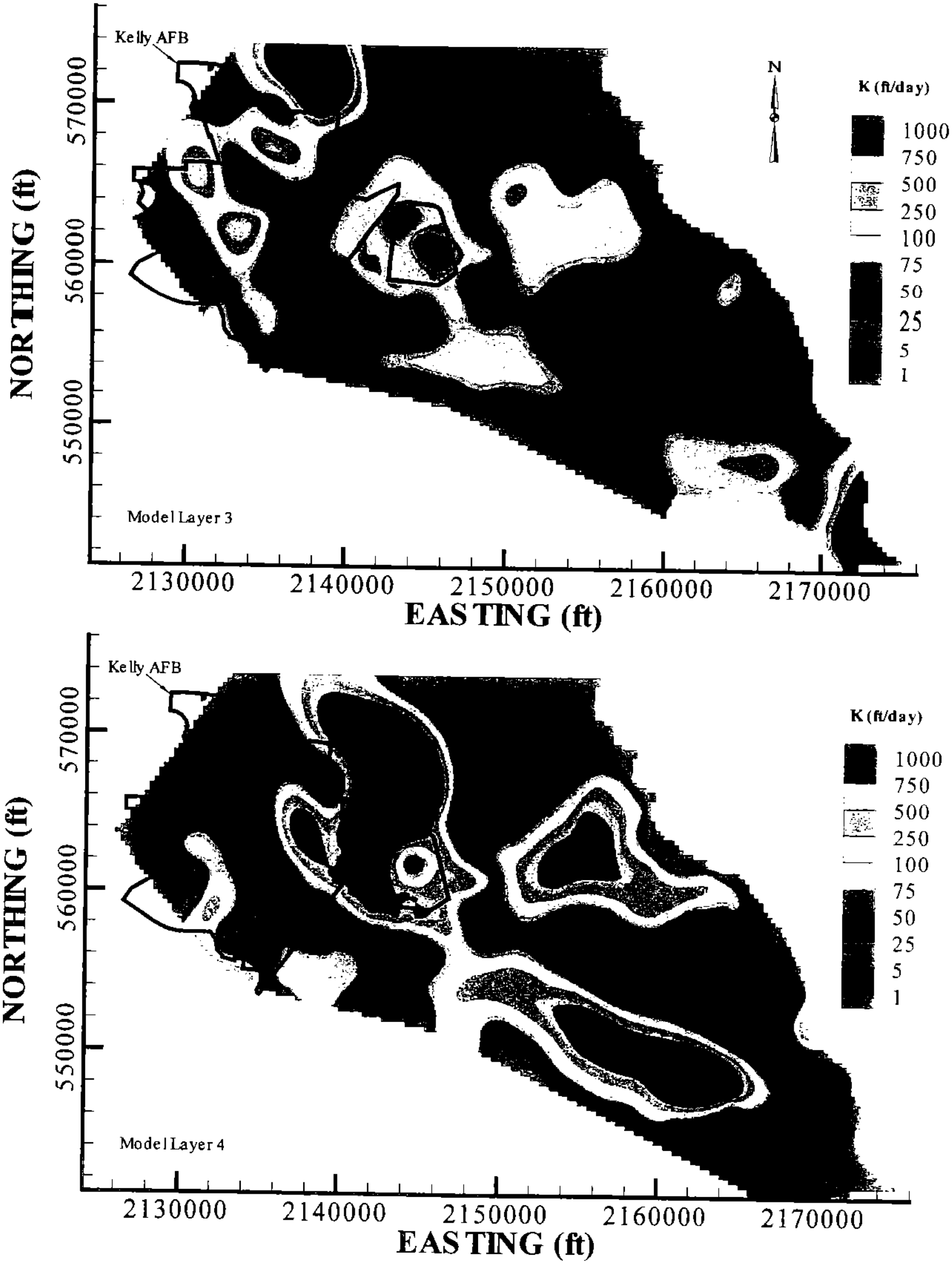


Figure 2-13 Hydraulic Conductivity Field Produced by the Expanded Basewide Model Calibration.

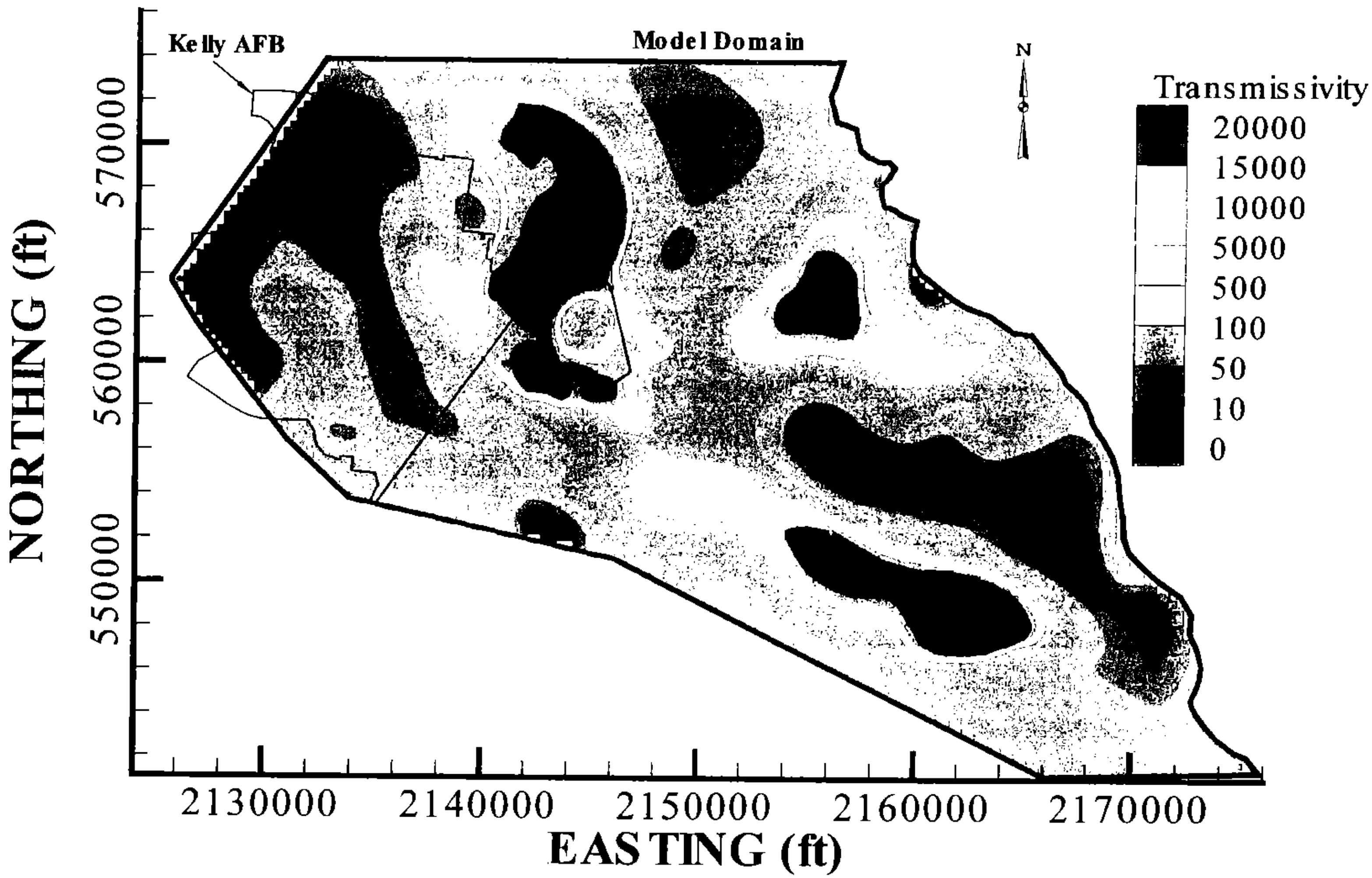


Figure 2-14 Transmissivity (ft^2/day) Field Produced by the Expanded Basewide Model Calibration

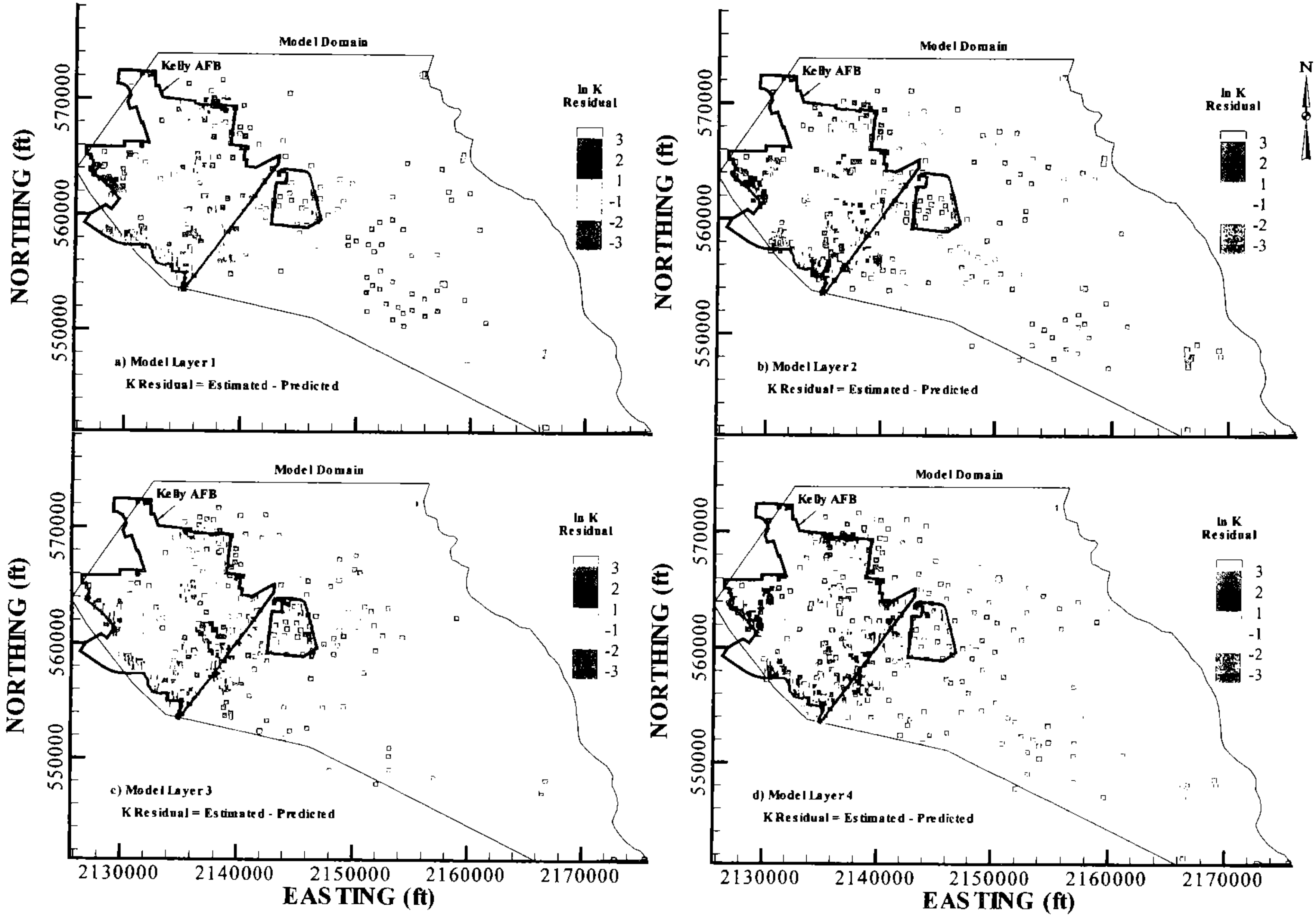


Figure 2-15 Ln (K) Residual – K Differences Between Estimated and Model Predicted Values

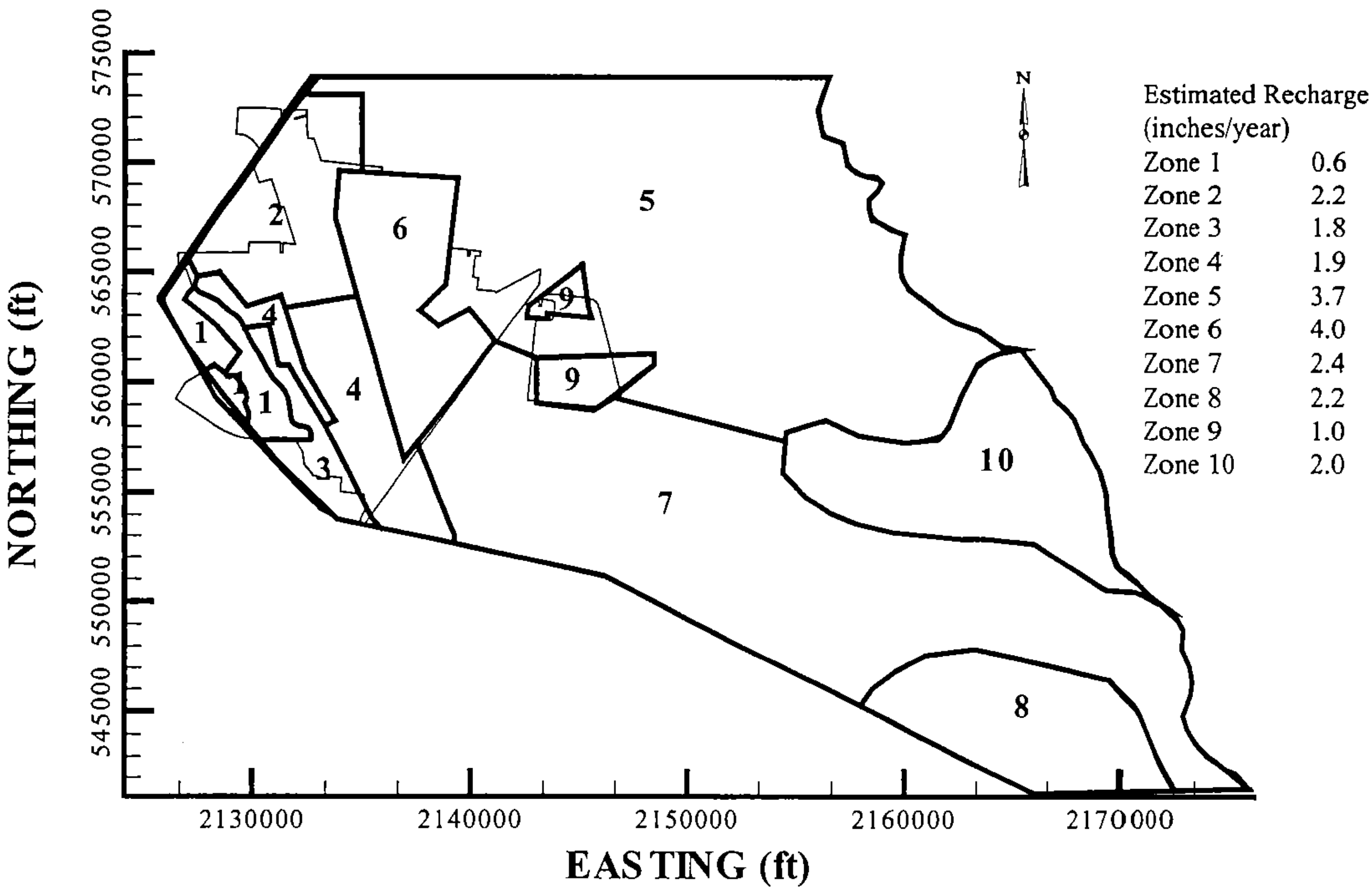


Figure 2-16 Recharge Distribution Produced by the Expanded Basewide Model Calibration

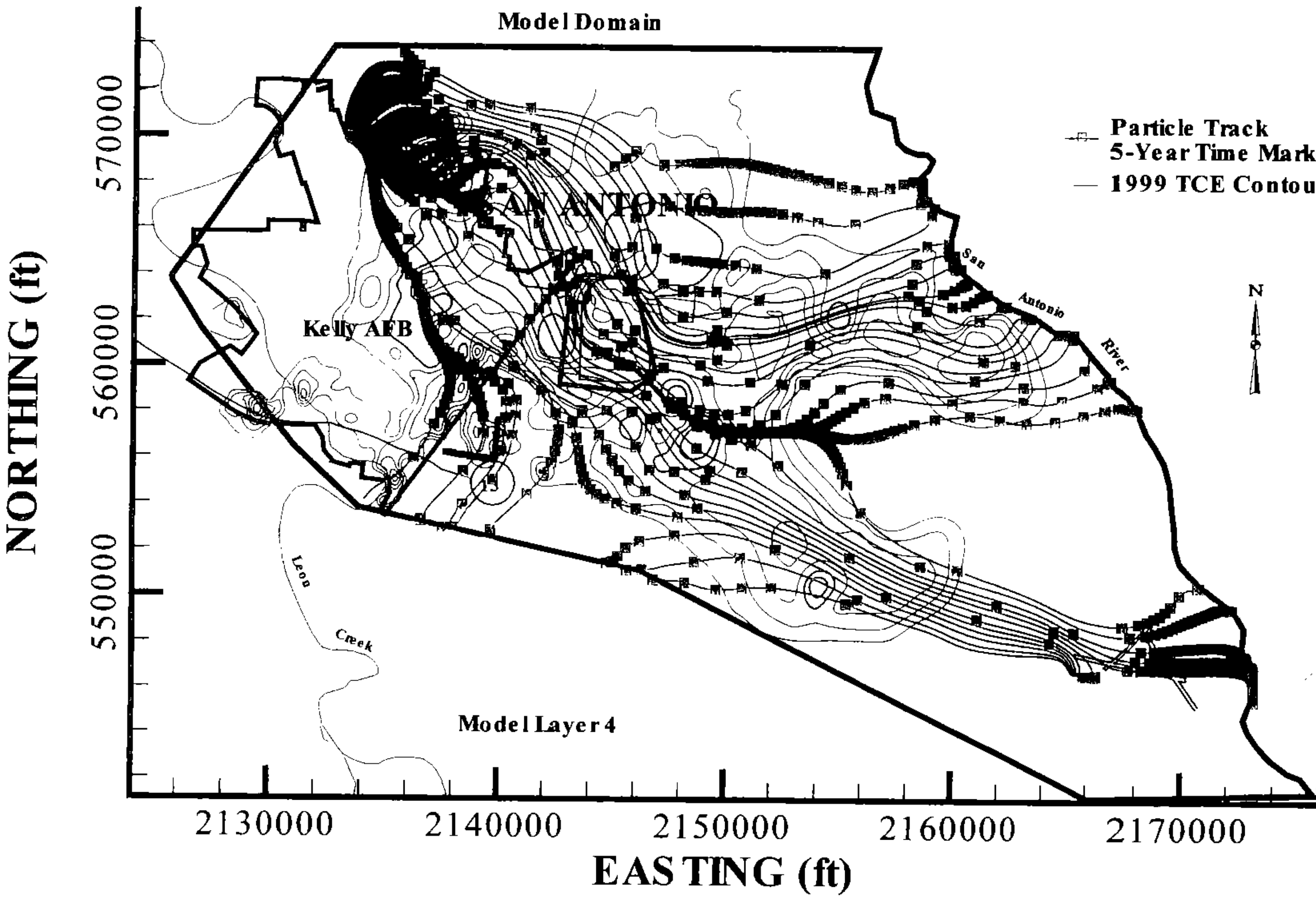


Figure 2-17 Flow Pathline Generated from the Expanded Basewide Model Calibration Via Particle Tracking

3.0 DEVELOPMENT OF TRANSPORT MODEL PARAMETERS

3.1 AQUIFER PROPERTIES

In order to simulate solute transport, effective porosity, dispersivity, and retardation parameters must be distributed in three-dimensions. The distribution of these values is based on a conceptual model developed from alluvial aquifer characterization data from the site.

3.1.1 Effective Porosity

Porosity is defined as the volume of voids divided by the total volume of the aquifer material including both the solid portion and the void space. Effective porosity represents that portion of the void spaces that is interconnected and capable of transmitting fluid. Thus, effective porosity is less than or equal to the total porosity. Effective porosity is used to calculate average linear ground-water velocity. For Zone 4 off-base transport simulation, an effective porosity of 30% is used for most of the alluvial aquifer deposits at the site.

The effective porosity of 30% represents an average of a range of values used at Kelly AFB before 1998, when HydroGeoLogic created its first basewide flow model at Kelly AFB. Since 1998, HydroGeoLogic has used 30% effective porosity for transport simulation at Site S-4 (HydroGeoLogic, 1999b) and Zone 5 (HydroGeoLogic, 2000b). Another justification for using an effective porosity of 30% is that it leads to credible ground water path line and velocities (see Figure 2-17).

3.1.2 Dispersivity

Hydrodynamic dispersivity is the parameter that describes the mixing of solute in ground-water, and incorporates the effects of both molecular diffusion and mechanical dispersion. Mechanical dispersion represents mixing caused by local variations in the ground-water velocity field. Except for systems in which ground-water velocities are very low, mechanical dispersion is significantly greater than molecular diffusion. For a steady-state flow field, mechanical dispersion accounts for plume spreading in the aquifer. The lateral transverse spreading will typically be much smaller than the longitudinal transverse spreading, and in turn, the vertical transverse spreading will be much smaller than the lateral transverse spreading.

Numerous field studies have demonstrated that mechanical dispersion is controlled by aquifer heterogeneity, temporal variations in the hydraulic gradient, and the size and location of the initial plume. The conventional method for modeling dispersion is to presume a Fickian (i.e. Gaussian) dispersion process in three-dimensions similar to molecular dispersion wherein a directional-dependent dispersivity value is used instead of a molecular diffusion coefficient.

The most comprehensive compilation of field data is presented by Gelhar et al. (1992). Gelhar et al. (1992) suggest that reasonable estimates of longitudinal dispersivity are between 1 to 20 feet with the greater values associated with the most heterogeneous aquifers. Given the fluvial deposition of the Kelly aquifer an upper value of 15 ft for the longitudinal dispersivity is reasonable. Gelhar et al., (1992) report ratios of longitudinal to lateral transverse dispersivity from about 1/5 to about 1/20. Because of the very heterogeneous nature of the deposits at Kelly AFB, a low ratio of 1/5 was used. Thus, the lateral transverse dispersivity is 3 feet. Numerous field results and the theoretical results of Gelhar et al., (1992) indicate that vertical transverse dispersivity values are typically 100 times smaller than lateral transverse dispersivity and thus are on the order of molecular diffusion. For the model simulations the vertical transverse dispersivity was set to 0.05 feet.

3.1.3 Adsorption

Adsorption of chlorinated solvents onto soils is based on retardation factors (R_f), which represents the ratio between the total solute mass (including both adsorbed and dissolved) to the solute mass dissolved in ground water. It is calculated using the following equation:

$$R_f = 1 + (\rho/n) * (f_{oc} * K_{oc})$$

Where:
- ρ = bulk density
- n = porosity
- f_{oc} = fraction of organic carbon
- K_{oc} = organic carbon/water partition coefficient

Table 3-1 summarizes the retardation factors calculated for the four chlorinated solvents of interest at site. The calculations are based on a porosity of 0.3, a bulk density of 1.7 grams per cubic centimeter (gm/cm^3), a fraction of organic carbon of 0.0158%, and an organic carbon/water partition coefficient shown in Table 3-1. Estimates of soil f_{oc} values are based on nine total organic carbon (TOC) measurements listed in Table B-2 of Site S-4 CMS report. The nine values range from 100 mg/Kg to 180 mg/Kg, and have an average of 158 mg/Kg. These nine measurements are different from most of the TOC measurements at Kelly AFB because the TOC analysis was performed with a pre-digestion step for removal of inorganic carbon contributions.

The calculated retardation factors range from 1.3 to 1.0. The higher the retardation factor the greater the adsorption and thus the greater the solute movement is retarded as compared to the ground-water migration. The magnitude of the retardation factor is the factor by which the average solute velocity is slower than the average ground-water velocity.

Table 3-1
Calculated Retardation Factors for PCE, TCE, DCE, and VC

Chlorinated Compound	Retardation Factor	K_{oc}	
		Value	Reference
PCE	1.3	364	Pankow and Cherry, 1996
TCE	1.1	126	Pankow and Cherry, 1996
DCE *	1.1	86	Pankow and Cherry, 1996
VC	1.0	2.5	Montgomery and Welkom, 1990

Note: K_{oc} is dependent on the DCE isomer. The reported value is for cis-1,2 DCE.

3.2 BIODEGRADATION RATES OF CHLORINATED SOLVENTS

Numerous studies have found that chlorinated solvents are recalcitrant in aerobic aquifers, but undergo varying degrees of degradation anaerobically (McCarty and Semprini, 1992). In fact, all of the chlorinated solvents have been shown to degrade anaerobically, although the transformation rates diminish with each dechlorinated daughter product (Vogel et al., 1987; Freedman and Gossett, 1989). Less chlorinated compounds have been found to degrade aerobically (Wilson and Wilson, 1985). If either the aerobic or the anaerobic approaches appear to be inadequate in a given situation, the potential exists to incorporate both approaches into a sequential bioremediation system (Fathepure and Vogel, 1991).

Under natural anaerobic conditions the highly chlorinated solvents are thought primarily to degrade through a process called reductive dechlorination. Reductive dechlorination involves the removal of a chlorine atom and its replacement with a hydrogen atom. For a compound such as PCE the sequence is generally as follows: PCE → TCE → DCE (primarily cis) →VC → ethene + ethane or CO2 + H2O. During reductive dechlorination, the chlorinated compound is used as an electron acceptor, and consequently, an electron donor is required for the process. Candidates for electron donors include natural organic carbon present in the aquifer or other contaminants such as benzene, toluene, ethylbenzene, and xylenes compounds. The lack of an electron donor can severely inhibit reductive dechlorination.

As discussed by HydroGeoLogic (1999b), the degradation rates for solvent compounds are affected by several factors of which redox conditions (e.g. aerobic or anaerobic) is an important one. As a general rule, the more chlorinated a solvent, the greater its degradation rate in anaerobic environments. Conversely, another general rule is that the less chlorinated a solvent, the greater its degradation rate in aerobic environments.

At Site S-4, a detailed analysis was performed on an extensive set of geochemical and solvent concentration data by HydroGeoLogic (1999b). Based on a joint analysis of break-through curves and numerical modeling results, the first-order biodegradation half-lives selected for the anaerobic zone of Site S-4 are 4 years, 4 years, 3 years, and 2 years, for PCE, TCE, DCE, and VC, respectively (HydroGeoLogic, 1999b). The term anaerobic zone refers to the region of the plume, where Dissolved Oxygen (DO) and Redox Potential (ORP) values are consistently less than 0.5 mg/l and -50 mV. For the transitional and aerobic regions of Site S-4, the model simulations suggested higher values of half-lives for PCE and TCE and lower values of half-life for VC. CH2M Hill provided HydroGeoLogic with a dataset of 20 Zone 4 off-base samples analyzed in December 1999. The range for DO is from 1 to 3 ppm with an average of 2 ppm, and the range for ORP is from 14 to 247 mV with an average of 121 mV. It appears that the Zone 4 off-base area is more transitional to aerobic condition compared to Site S-4 environment, where there is abundant carbon organic supply.

Table 3-2 provides a summary of biodegradation rates developed in Site S-4 showing general agreement among the different approaches for estimating the half-lives, although each approach has its own inherent limitations. The two methods associated with the analysis of breakthrough curves assume one-dimensional flow, a pathline with a constant velocity along the plume centerline, a rectangular source with a constant concentration, and no chain decay. Between the two break-through methods, the method of Buscheck and Alacantar (1995) accounts for hydrodynamic dispersion and for a procedure to generate a best-fit solution to the measured data points. The inherent limitations associated with the numerical modeling approach are directly determined by the validity of the site's conceptual model and the calibration of the numerical model. Given that the numerical model was developed to account for the complexities of ground water flow, aquifer characteristics, and geochemical environment at Site S-4, the biodegradation rates from the modeling results are considered the most reliable.

Table 3-2
Summary of Degradation Half-Lives (yr) Used for Transport Simulation at Site S-4 and Zone 4 Off-base for PCE, TCE, DCE, and VC

	Site S-4			Zone 4 Off-base
	Numerical Modeling Results	Breakthrough Curve Analysis		
		Method of Buscheck & Alcantar (1995)	Visual Inspection of Linearly Plotted Values	
PCE	~2	2.3 - 3.0	2-4	8
TCE	~2	2.4 - 3.0	2-4	6
DCE	~3	NVC	3	8
VC	~~0.75 to <2.5	NVC	2	1

note: NVC = No Values Calculated

It is noted that in the existing Zone 4 off-base plume contour maps, in contrast to its parent and grandparent compound, the VC plume is narrow. Field data suggests that PCE and TCE on site were naturally biodegrading to DCE, but biodegradation may slow down due to insufficient availability of the necessary bacteria for sequentially biodegradation to

VC. For this reason, the half-life for DCE should be greater than that for TCE. A recent biotreatability lab study has confirmed that this process is occurring at the site (GeoSyntec Consults, 2000).

Based on the limited geochemical information, the absence of any man-made carbon-source plume delineations, and the small VC plume, Zone 4 off-base is presumed to have plumes with redox potentials characterized by transitional to aerobic conditions. For this condition, the assumptions of half-lives of 8 year for PCE, 6 years for TCE, 8 years for DCE, and 1 year for VC are reasonable. Table 3-2 lists a summary of half-life used for transport simulation.

4.0 SIMULATION OF ZONE 4 OFF-BASE FLOW MODEL

Per request of the TNRCC Permit/Compliance Plan to Kelly AFB, an RFI/CMS activity was conducted at IRP Zone 4. This was expanded to include the ground water that was potentially affected by IRP Site MP (outside the slurry wall containment system), and to the east off-base for ground water being impacted by Sites MP and SS051 on East Kelly. As part of this activity, a set of potential remediation options was proposed.

As introduced in the background Section 1, contaminant transport simulations of remediation alternatives typically require a significantly finer grid discretization than does the ground-water flow simulations, in order to reduce numerical dispersion of the contaminant plume front. A zoom model with a refined numerical grid can either be developed within or be cut from the basewide ground-water flow model. The rationale for using a refined grid discretization in the zoom flow model is to accurately represent both steep hydraulic gradients near extraction wells and aquifer heterogeneity. The objectives of computational efficiency and the minimization of numerical error will guide the construction of a zoom model's discretization.

A Zone 4 off-base zoom model was developed for use to evaluate remediation alternative to support RFI/CMS. This section describes development of the Zone 4 off-base flow model, with the next section focusing on its applications to remediation alternatives. A Site MP zoom model was also developed during this study for characterizing a source term at Site MP. Simulation results of the MP zoom model are documented in Appendix A.

4.1 MODEL FRAMEWORK

Figure 4-1 displays the numerical grid for the Zone 4 off-base zoom model embedded within the expanded basewide model and superimposed on an area map, which extends from a central base ground water divide to the east. The numerical mesh of the Zone 4 off-base model has spacing of 300-ft, 100-ft, and a 50-ft, with the smallest grid space occurring at the vicinity of East Kelly remediation system. The numerical grid consists of 109 rows and 173 columns of cells, for a total of 18,857 grid cells in each of the 4 model layers.

The hydraulic boundaries and aquifer properties of the zoom model were extracted from the portion of the basewide model that incorporates the area of interest. Hydraulic boundaries for the perimeter of the zoom model were interpolated from the boundary hydraulic head values in the basewide model. These boundary heads incorporate the effects of stresses (i.e., pumping) and features located in the basewide model but outside the zoom model boundary, and act to transfer those effects into the zoom model simulation. Hydraulic boundary conditions within the perimeter of the zoom model such as recharge at the water table, no-flow at the Navarro clay interface, pumping rates at well screen locations, and drain and river elevations along streams are the same as those used in the basewide model. All aquifer hydrogeological properties controlling groundwater flow, such as hydraulic conductivity, were interpolated onto the elements of the zoom model from elements in the basewide ground-water flow model.

Figure 4-2 shows locations and extraction rates of newly installed East Kelly horizontal and vertical wells, in addition to MP wells within the Zone 4 off-base model domain. There is no water table measurement data available during pumping periods at East Kelly. The proposed extraction rates listed in Figure 4-2 were used to simulate head condition of zoom model for pumping. The model simulation was run to represent annual conditions under steady state.

4.2 SIMULATED FLOW FIELD FOR PUMPING

Figure 4-3 displays the simulated hydraulic head distribution represented by model layer 4 for pumping scenario. It appears the drawdown is significant only in locations of well placement. Table 4-1 shows the water budget for the pumping run. The water budget for this simulation has a mass balance error that is less than 1%.

Table 4-1
Calculated Ground-Water Fluxes (ft^3/day) for
Simulated East Kelly and Site MP Extraction Systems

	Recharge	Well	Drain	River	Model Boundary	Total Flux
In	462220	0	0	220600	671420	1354240
Out	-51266	-99812	-598	-738300	-475590	-1365566
Net	410954	-99812	-598	-517700	195830	-11326
Mass Balance Error						-0.84%

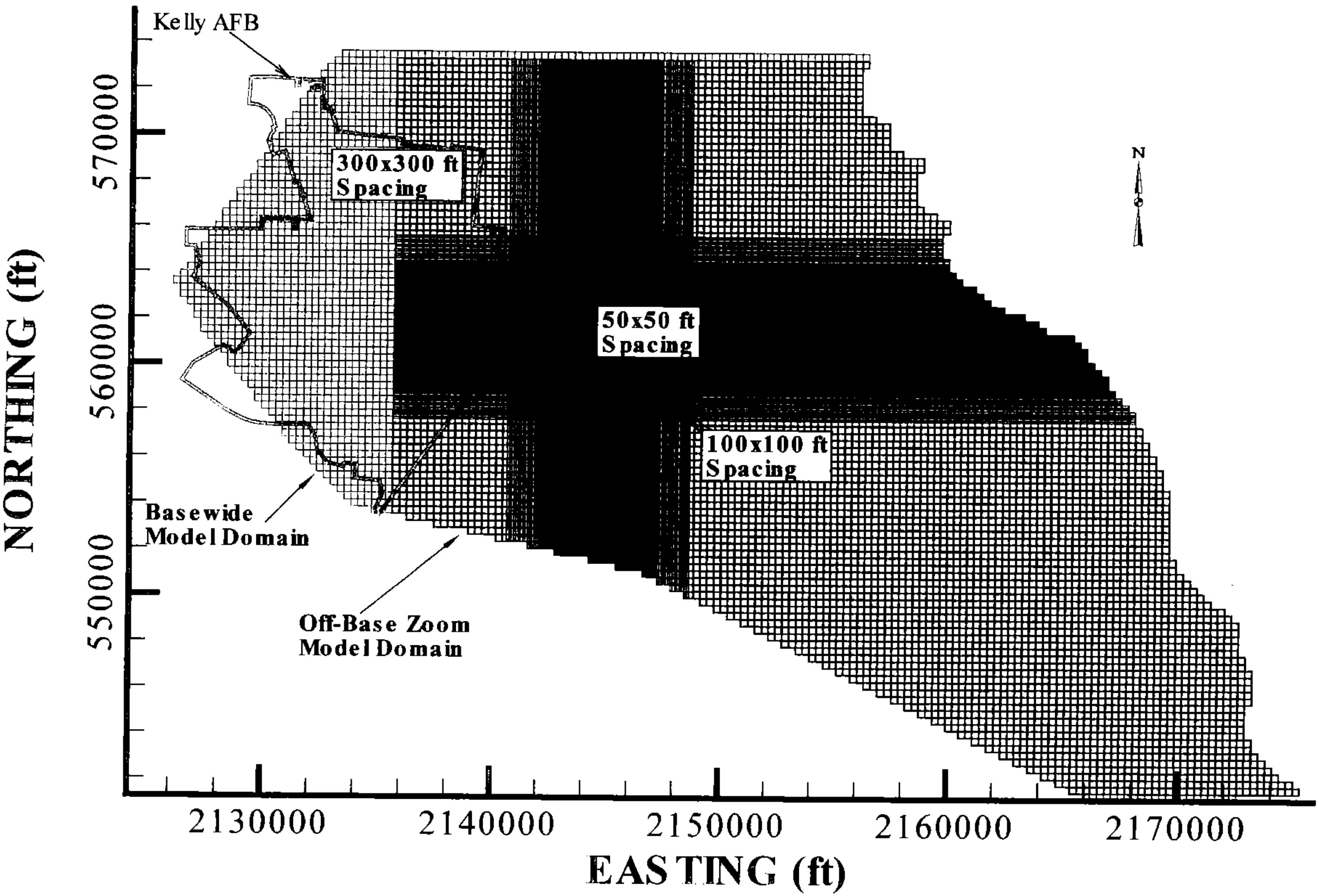
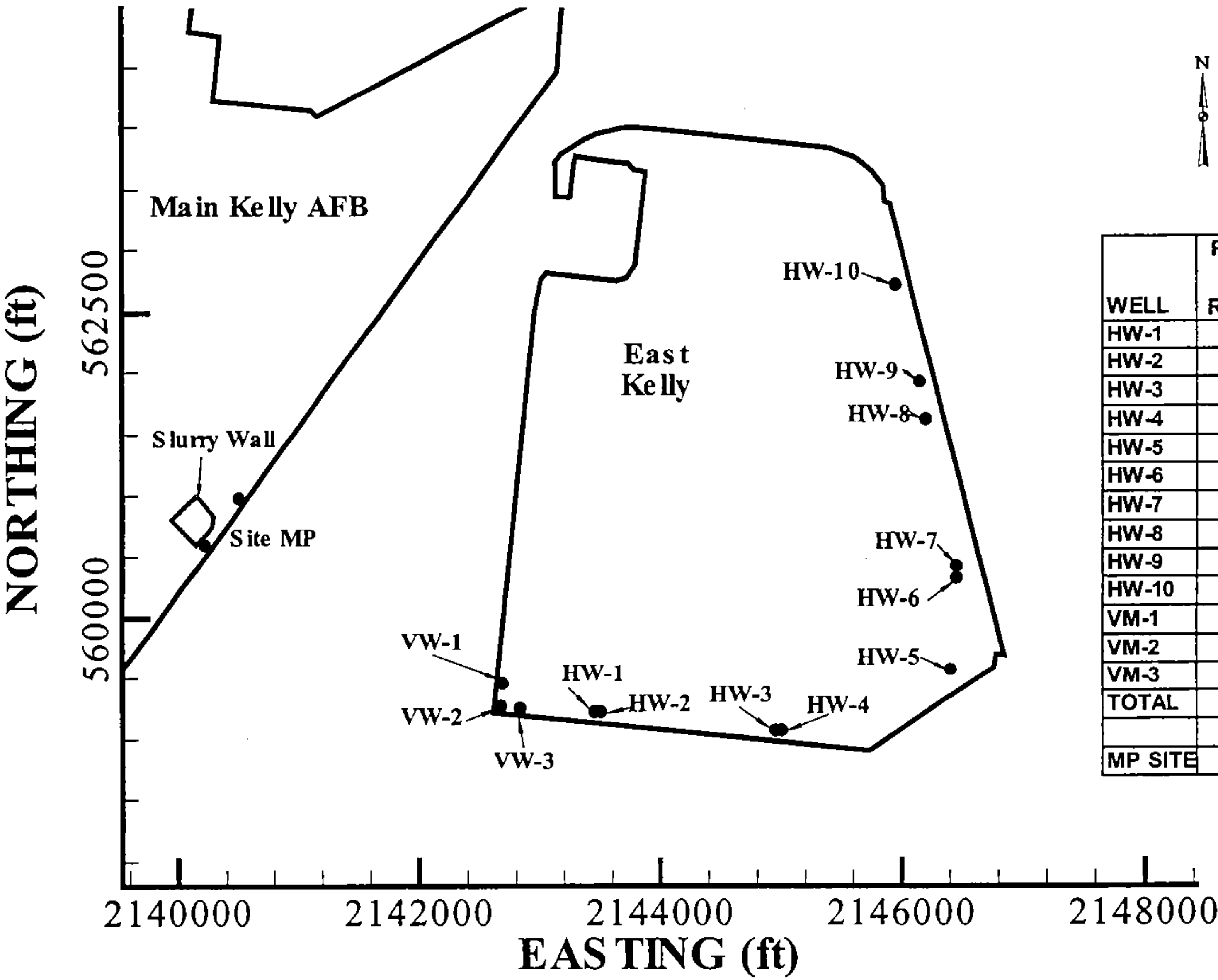


Figure 4-1 Numerical Grid of Off-Base Zoom Model Embedded within the Expanded Basewide Model



WELL	PROPOSED PUMPING RATE (GPM)
HW-1	72
HW-2	25
HW-3	11.5
HW-4	30
HW-5	35
HW-6	30
HW-7	30
HW-8	30
HW-9	50
HW-10	50
VM-1	35
VM-2	25
VM-3	25
TOTAL	448.5
MP SITE	70

Figure 4-2 Locations of Existing East Kelly and Site MP Remediation Well Networks

5.0 SIMULATION OF REMEDIATION OPTIONS

The refined Zone 4 off-base zoom model was used to simulate fate and transport of PCE, TCE, DCE, and VC for different remediation options. Model simulations were performed in a phased approach. The Phase 1 simulations were performed for all twelve possible remediation options. Simulation results were screened for both technical criteria as well as community acceptance criteria during development of the CMS. Phase 2 simulations were conducted for only six of the most feasible remediation options.

One of differences between Phase 1 and Phase 2 simulations is the determination of the contaminant source terms for model input. Site MP, located on Main Kelly, and Site SS051, located on East Kelly, have been determined to be the primary source of chlorinated solvents in ground water migrating off-base. The exact age and source mass of the PCE and TCE releases are unknown. For the Phase 1 simulations, the two source areas were assumed as continuing, but decreasing for the next 35 years. The simulation results based on this conservative assumption were used to support a risk assessment as part of RFI/CMS, and were presented to public and stakeholders in winter 2001 meetings. In order to provide a conservative estimate of concentration for a risk assessment, source containment such as a slurry wall at Site MP was not fully factored in, and no control was placed at Site SS051 for the Phase 1 simulations. The model input for Phase 2 simulation takes into account of the existing and potential source controls at the MP and SS051 sites. Both simulations were based on an assumption that remediation options are throughout the entire period of simulation time.

This section will describe remediation objective and approach, and model parameters for simulation, and then present simulation results for both two phases. The model development and simulation results of the Site MP zoom model are documented in Appendix A.

5.1 REMEDIATION OBJECTIVES

The objective for remediation of ground water in the alluvial aquifer beneath Zone 4 off-base plumes is to reduce solvent contaminants and improve the quality of ground water to meet the Maximum Contaminant Levels (MCLs) under federal drinking water standards.

The MCLs for PCE, TCE, DCE (mainly 1,2-cis DCE), and VC are 5 ppb, 5 ppb, 70 ppb, and 2 ppb, respectively.

5.2 POTENTIAL REMEDIATION OPTIONS

Kelly AFB has proposed twelve remediation options for cleanup of Zone 4 off-base plume. Table 5-1 summarizes each remediation option and places them into two groups according to community criteria and technical standard and practicality for implementation during RFI/CMS evaluation process. Community criteria include health, property values, cleanup time, and community disruptions. Technical standards consist of cleanup time, effectiveness, and construction issues. The most feasible group has remediation options A1, B, C1, D, E1, and F. The least feasible group includes remediation options A, C, E, G, H, and I. A baseline design, designated as Option D, consists of the existing system that includes ten newly installed horizontal wells, three vertical extraction wells at East Kelly, and two existing extraction wells at Site MP. All other options can be considered as supplemental to Option D existing source control and monitored natural attenuation. In this report, the Option D is also referred to as baseline.

Table 5-1
Twelve Remediation Options for Phase 1 Simulations

MOST FEASIBLE	
Option A1	Pump and Treat with Horizontal Wells down Centerline of Plume Lobe with GW Interception Trench at River
Option B	Pump and Treat at Areas of Higher Concentration with Phytoremediation along River
Option C1	Pump and Treat down Centerline of Plume Lobes with Reinjection
Option D	Existing Source Control Systems and Monitored Natural Attenuation
Option E1	Flow-Through Reactive Walls down Centerline of Plume Lobes
Option F	Flow-Through Reactive Walls at Areas of Higher Concentration
LEAST FEASIBLE	
Option A	Pump and Treat with Horizontal Wells Plumewide with GW Interception Trench at River
Option C	Pump and Treat Plumewide with Reinjection
Option E	Flow-Through Reactive Walls Plumewide
Option G	Microorganism Breakdown at Areas of Higher Concentration
Option H	Oxygen Treatment at Areas of Higher Concentration
Option I	Air Injection/Vapor Removal at Areas of Higher Concentration

Options A1, B, C1, A, and C involve additional pumping. Different well placement schemes of horizontal wells or trenches are targeted to the extent of the higher concentration area or the whole plume, designated as contaminant concentrations above their respective MCLs. Option A1 has horizontal wells down the centerline of the plume lobe, and a ground water intercept trench along the San Antonio River. Option C1 has the same horizontal wells as Option A1, with additional reinjection wells. Option B has limited horizontal wells placed in the plume with elevated concentration and phytoremediation along the river. Options A and C have the most intensive horizontal wells and reinjection wells placement plume wide. Because of the associated cost and disturbance, options A and C are deemed least feasible.

All horizontal and reinjection wells are placed in the model cells with alignments to the street orientation, mostly north-south. The flux out of aquifer for those horizontal well cells was calculated based on a saturated thickness of 2-foot above the bottom of model layer 4, then, this flux represents the maximum extraction rate for those cells for horizontal wells. Reinjection wells were placed about 900 to 1200 feet west, up-gradient of each line of horizontal well cells in the model. Reinjection was represented with a rate based on the flux from the down-gradient cells. All simulations were run under steady-state flow conditions. The mass balance error for each simulation was less than 1%. The simulated head field for baseline Option D is presented in Figure 4-3 of Section 4.

5.3 TRANSPORT MODEL SET-UP

The aquifer and chemical parameters associated with the transport model are presented in Sections 3 and 4. All of the simulations included adsorption, dispersion, and biodegradation for PCE, TCE, DCE, and VC for the Zone 4 off-base model. Every transport simulation was run for 35 years in Phase 1 and for 25 years in Phase 2. For every model time-step interval, a comprehensive mass balance was calculated. The initial time interval was set to 0.0001 days and the maximum time interval was set to 20 days. Complete concentration distributions for all four chlorinated solvents were saved at 5-year intervals. For a single model run, the total amount of computer hard-drive space for input, output, and processing space is approximately 400 megabytes.

5.3.1 Source Terms

For the Phase 1 transport simulations, two on going, but declining, source terms were assigned to the MP and SS051 sites, as shown in Figure 5-1. Table 5-2 shows concentration levels estimated for the two PCE and TCE source terms. The source concentrations were based on high end of analytical data as dissolved phase, and an assumption that the residual source, although declining, will exist for the entire period of model simulation. The PCE source at Site MP was assigned to three model cells covering 45,000 square feet. This area is where a DNAPL pool has been discovered. The TCE source at the SS051 site was assigned to four model cells covering 10,000 square feet. This area is near the monitoring well SS004MW010. Both source terms were active in model layers 2, 3, and 4.

Table 5-2
Estimated Source Terms for Transport Simulation (Phase 1)

Stress Period	Time (years)	Period	MP Source	SS051 Source
			PCE (ppb)	TCE (ppb)
1	10	2001-2010	1000	500
2	10	2011-2020	800	400
3	10	2021-2030	600	300
4	5	2031-2035	400	200

5.3.2 Initial Contaminant Distribution

The existing plume conditions based on combined 1999-2000 field data were used for input as initial contaminant distribution for transport simulation. Kelly AFB provided HydroGeoLogic with AutoCAD files of PCE, TCE, DCE, and VC contour maps in concentration intervals of 1 to 1000 ug/l. The initial mass distribution for the four species is based on interpolation between the contours. For instance, between the 0 (i.e.

no detect) and 5 ppb contours, the concentration values range between 0 and 5 ppb. The initial contaminant mass based on the concentration contours was assigned to model layers 3 and 4.

5.3.3 Biodegradation Rates For Remediation Options

In additional to Option D baseline pumping, Option B has limited pumping with phytoremediation in the north lobe of plume along the river. Options E, E1, F, G, H, and I involve enhanced biodegradation either using flow-through reactive walls, or placing biotreatment cells at higher concentration spots. All bioenhancement options were simulated using various biodegradation rate assignments to the model cells within these biotreatment placements. Locations of model cells with enhanced biotreatment options are given in 5-year plume plots for that individual option. Table 5-3 lists biodegradation rates for these specified cells of each option. The ranges of biodegradation rates were determined based on their expected relative effectiveness for each option to degrade solvent compounds.

Table 5-3
Degradation Rates (Half-Life, Years) at Model Cells
with Enhanced Biodegradation Options

Options	Cell Specifications	PCE	TCE	DCE	VC
B	Phytoremediation along the River	0.001	0.001	0.001	0.001
E, E1, F	Flow-Through Reactive Walls	0.001	0.001	0.001	0.001
G	Microorganism Breakdown	2	1.5	2	0.25
H	Oxygen Treatment	1	0.75	1	0.125
I	Air Injection/Vapor Removal	4	3	4	0.5

5.4 SIMULATION RESULTS OF REMEDIATION OPTIONS (PHASE 1)

Model simulation results for each remediation option are summarized using plots of concentration distributions at 5-year time intervals starting at FY 2000 (i.e. at 0 year) and ending at FY2025 (i.e. at 25 years) (Figure 5-2 through Figure 5-38). The concentration plots show the area enclosed by the MCL levels of 5 ppb, 5 ppb, and 2 ppb for PCE, TCE, and VC, respectively. Concentration plots of DCE are only shown for the Option D baseline case (Figure 5-4) as an example due to simulation results indicating DCE concentrations below MCLs at all time intervals.

To aid discussions based on concentration plots, a summary table was prepared to show the remaining area still above MCLs in percentage of the existing plume (FY 2000) at initial conditions for each compound and at 5-year intervals for the entire 35-year simulation (Table 5-4). The contaminant area was separated to East Kelly and off-base. East Kelly is the area enclosed by the East Kelly base boundary. Off-base covers the area

Table 5-4 (a)
Area Remaining PCE Contaminanted in Acre and Percentage (Phase 1)

Years	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent
Most Feasible Options												
Off-Base	Option D		Option B		Option F		Option A1		Option C1		Option E1	
0	4158		4158		4158		4158		4158		4158	
5	1463	35.2%	1356	32.6%	1235	29.7%	1038	25.0%	1031	24.8%	1275	30.7%
10	337	8.1%	291	7.0%	239	5.8%	199	4.8%	200	4.8%	254	6.1%
15	63	1.5%	80	1.9%	61	1.5%	92	2.2%	94	2.3%	61	1.5%
20	18	0.4%	40	1.0%	16	0.4%	56	1.4%	56	1.4%	16	0.4%
25	1	0.0%	20	0.5%	1	0.0%	36	0.9%	36	0.9%	1	0.0%
30	1	0.0%	19	0.5%	1	0.0%	35	0.8%	35	0.9%	1	0.0%
35	0	0.0%	13	0.3%	0	0.0%	24	0.6%	24	0.6%	0	0.0%
East Kelly												
0	179		179		179		179		179		179	
5	9	5.0%	11	6.3%	9	4.9%	5	2.8%	5	3.0%	8	4.6%
10	0	0.0%	1	0.5%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
15	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
20	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
30	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
35	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Least Feasible Options												
Off-Base	Option A		Option C		Option E		Option G		Option H		Option I	
0	4158		4158		4158		4158		4158		4158	
5	838	20.2%	823	19.8%	1069	25.7%	1387	33.3%	1357	32.6%	1433	34.5%
10	154	3.7%	129	3.1%	177	4.3%	280	6.7%	253	6.1%	312	7.5%
15	75	1.8%	73	1.8%	60	1.4%	61	1.5%	60	1.4%	62	1.5%
20	37	0.9%	37	0.9%	16	0.4%	15	0.4%	14	0.3%	17	0.4%
25	17	0.4%	18	0.4%	1	0.0%	0	0.0%	0	0.0%	0	0.0%
30	17	0.4%	17	0.4%	1	0.0%	0	0.0%	0	0.0%	0	0.0%
35	11	0.3%	12	0.3%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
East Kelly												
0	179		179		179		179		179		179	
5	0	0.0%	0	0.1%	8	4.6%	8	4.6%	8	4.6%	9	4.9%
10	0	0.0%	0	0.2%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
15	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
20	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
30	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
35	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%

Table 5-4 (b)
Area Remaining TCE Contaminanted in Acre and Percentage (Phase 1)

Years	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent
Most Feasible Options												
Off-Base	Option D		Option B		Option F		Option A1		Option C1		Option E1	
0	3622		3622		3622		3622		3622		3622	
5	2762	76.3%	2212	61.1%	2142	59.1%	1515	41.8%	1482	40.9%	2292	63.3%
10	1616	44.6%	856	23.6%	702	19.4%	439	12.1%	463	12.8%	761	21.0%
15	196	5.4%	126	3.5%	74	2.0%	60	1.7%	64	1.8%	74	2.0%
20	39	1.1%	40	1.1%	38	1.0%	34	0.9%	29	0.8%	38	1.0%
25	16	0.4%	16	0.4%	15	0.4%	11	0.3%	6	0.2%	15	0.4%
30	13	0.4%	15	0.4%	13	0.4%	11	0.3%	6	0.2%	13	0.4%
35	11	0.3%	13	0.4%	11	0.3%	8	0.2%	4	0.1%	11	0.3%
East Kelly												
0	318		318		318		318		318		318	
5	173	54.4%	209	65.6%	173	54.4%	191	60.0%	191	60.0%	172	54.1%
10	169	53.0%	193	60.6%	169	53.0%	187	58.7%	187	58.6%	169	53.0%
15	163	51.2%	186	58.4%	163	51.2%	179	56.4%	179	56.2%	163	51.2%
20	161	50.6%	184	57.8%	161	50.6%	179	56.1%	178	55.9%	161	50.6%
25	154	48.4%	175	55.1%	154	48.4%	169	53.1%	169	53.0%	154	48.4%
30	151	47.5%	173	54.3%	151	47.5%	168	52.6%	167	52.4%	151	47.5%
35	140	44.1%	161	50.7%	140	44.1%	154	48.2%	152	47.8%	140	44.1%
Least Feasible Options												
Off-Base	Option A		Option C		Option E		Option G		Option H		Option I	
0	3622		3622		3622		3622		3622		3622	
5	1021	28.2%	608	16.8%	972	26.8%	2720	75.1%	2537	70.0%	2753	76.0%
10	170	4.7%	111	3.1%	342	9.4%	1259	34.8%	1073	29.6%	1492	41.2%
15	107	3.0%	64	1.8%	72	2.0%	115	3.2%	86	2.4%	160	4.4%
20	80	2.2%	41	1.1%	38	1.0%	39	1.1%	39	1.1%	39	1.1%
25	56	1.5%	15	0.4%	15	0.4%	16	0.4%	16	0.4%	16	0.4%
30	47	1.3%	13	0.4%	13	0.4%	13	0.4%	13	0.4%	13	0.4%
35	36	1.0%	6	0.2%	11	0.3%	11	0.3%	11	0.3%	11	0.3%
East Kelly												
0	318		318		318		318		318		318	
5	203	63.6%	193	60.7%	172	54.1%	191	60.0%	172	54.1%	173	54.4%
10	198	62.3%	187	58.6%	169	53.0%	187	58.7%	169	53.0%	169	53.0%
15	192	60.3%	180	56.5%	163	51.2%	179	56.4%	163	51.2%	163	51.2%
20	191	60.0%	179	56.1%	161	50.6%	179	56.1%	161	50.6%	161	50.6%
25	181	57.0%	169	53.2%	154	48.4%	169	53.1%	154	48.4%	154	48.4%
30	180	56.5%	168	52.6%	151	47.5%	168	52.6%	151	47.5%	151	47.5%
35	165	51.9%	153	48.2%	140	44.1%	154	48.2%	140	44.1%	140	44.1%

Table 5-4 (c)
Area Remaining VC Contaminanted in Arce and Percentage (Phase 1)

Years	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent
Most Feasible Options												
Off-Base	Option D		Option B		Option F		Option A1		Option C1		Option E1	
0	32		32		32		32		32		32	
5	414	1293%	422	1318%	286	894.1%	103	320.4%	119	372.4%	322	1006%
10	290	906.5%	292	912.2%	92	288.2%	0	0.0%	12	37.6%	87	273.1%
15	21	64.5%	36	112.9%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
20	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
30	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
35	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
East Kelly												
0	6		6		6		6		6		6	
5	16	269.5%	15	241.0%	16	269.5%	22	372.4%	22	365.7%	16	269.5%
10	17	286.7%	17	281.9%	17	286.7%	12	194.3%	12	196.2%	17	286.7%
15	10	162.9%	12	201.9%	10	162.9%	2	39.0%	4	59.0%	10	162.9%
20	0	0.0%	3	52.4%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	1.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
30	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
35	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Least Feasible Options												
Off-Base	Option A		Option C		Option E		Option G		Option H		Option I	
0	32		32		32		32		32		32	
5	34	105.4%	31	96.8%	219	682.4%	402	1255%	393	1226%	411	1283%
10	0	0.0%	0	0.0%	59	182.8%	277	863.4%	256	798.2%	285	889.2%
15	0	0.0%	0	0.0%	0	0.0%	8	25.8%	0	0.0%	14	45.2%
20	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
30	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
35	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
East Kelly												
0	6		6		6		6		6		6	
5	22	368.6%	18	290.5%	16	269.5%	16	269.5%	16	269.5%	16	269.5%
10	12	200.0%	4	66.7%	17	286.7%	17	286.7%	17	286.7%	17	286.7%
15	1	20.0%	0	0.0%	10	162.9%	10	162.9%	10	162.9%	10	162.9%
20	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
30	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
35	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%

beyond the base boundary. For better visualization, a pie chart showing the percentage of remaining contaminated area off-base in black was inserted into each corresponding 5-year concentration plots. A solid black circle represents the existing plume at 0 year condition, or decay products added to the existing plumes. A solid white circle indicates MCL attainment through out the entire off-base area.

5.4.1 Concentration Plots for Every 5 Years (Phase 1)

Concentration plots of Option D shown in Figure 5-2 through 5-5 provide a baseline case for comparisons. As an existing source control system, the majority of PCE and TCE generated from the source terms is stabilized and being contained within the base boundary, or near the base boundary. PCE and TCE plumes have essentially dissipated from off-base by 20 years. Slightly above MCL amounts of VC were generated as decay product on East Kelly and in the area to the southeast of East Kelly, but by 20 years VC concentration is below MCL in all model cells.

Figures 5-6 through 5-20 show 5-year concentration plots and associated pie charts for the rest of the most feasible remediation options. While the PCE and TCE sources are still well contained, the supplement options are mainly focused on speeding up cleanup of the off-base plume. In the time intervals of 5 to 10 years, areas of remaining contamination of PCE and TCE off-base are significantly reduced in proportion to the placement and effectiveness of selected remediation options.

The 5-year concentration plots and pie charts for the six least feasible remediation options are shown in Figures 5-21 through 5-38. Compared to its corresponding option of less intensive, in the most feasible group, (e.g., Option A to A1, Option C to C1, Option E to E1 and F), short term reduction was improved within each option, but no long-term differences exist after 20 years.

TCE is the most widespread and persistent contaminant among the four solvent compounds at site. For easy comparison of effectiveness among remediation options in term of reduction of area remaining contaminated, a bar chart breaking down four 5-year segments was created to show percentage of area remaining TCE contaminated off-base for the first 20 years of remediation (Figure 5-39). The majority of off-base reduction in contaminated areas occurs between 5 and 10 years. Within 15 to 20 years, area and maximum concentration reduction for each remediation option is virtually identical. It is noted that the PCE and TCE contaminations that persisted after 20 years are mostly from the source terms.

5.4.2 Time to Attain MCLs for PCE, TCE, and VC Concentrations (Phase 1)

Figures 5-40 through 5-51 show the change in the maximum concentration of PCE, TCE, and VC over time for the portions of the plume on East Kelly and off-base. Table 5-5 summarizes the time in years at which the maximum concentration has dropped below its MCLs for all remediation options.

At the initial 0 to 10 years, significant reductions of PCE and TCE occur for all remediation options represented by steep slope on the plots. Increasing VC concentrations result from degradation of parents PCE and TCE. From 10 to 20 years, PCE and TCE concentrations are tailing off. Very little change in concentrations occurs beyond 25 years. TCE contamination for both East Kelly and off-base has persisted at or beyond 35 years solely due to a continuing supply of contamination from the assumed source terms. By 20 years, the vast majority of the existing plume not associated with the two source terms has been dissipated through remediation. The plume addition from the source terms and elimination via remediation reach an equilibrium status.

Table 5-5
Time (years) for the Maximum Concentration to Reach the MCLs (Phase 1)

Options	PCE		TCE		VC	
Most Feasible	East Kelly	Off-base	East Kelly	Off-base	East Kelly	Off-base
Option A1	10	>35	>35	>35	15	10
Option B	15	>35	>35	>35	30	20
Option C1	10	>35	>35	>35	15	15
Option D	10	35	>35	>35	20	20
Option E1	10	35	>35	>35	20	15
Option F	10	35	>35	>35	20	15
Least Feasible	East Kelly	Off-base	East Kelly	Off-base	East Kelly	Off-base
Option A	5	>35	>35	>35	20	10
Option C	15	>35	>35	>35	15	10
Option E	10	35	>35	>35	20	15
Option G	10	25	>35	>35	20	20
Option H	10	25	>35	>35	20	15
Option I	10	35	>35	>35	20	20

One observation made from the Phase 1 simulation results is that even for this conservative approach, the majority of the FY2000 contaminant plume will be cleaned up after 20 years. The PCE and TCE plume that persists after 20 years is mainly derived from the MP and SS051 source terms. This shows that the best strategy for accelerating cleanup would be to control or remove source terms. If both source terms were significantly reduced, cleanup could be reduced to 20 years.

5.5 PHASE 2 SIMULATIONS OF REMEDIATION OPTIONS

Phase 1 simulations of Zone 4 off-base zoom model from a risk-based approach indicated that after 20 years, PCE and TCE plumes that persist both on East Kelly and off-base are mainly derived from the two MP and SS051 source terms. Recent monitoring well data suggests that a continuing source term is not consistent with installation and operation of active remediation systems on site. Concentration levels of hot spot wells outside of the slurry wall are declining since installation of remediation systems. Results of remediation alternative simulation of Site MP zoom model documented in Appendix A indicate if contaminated source term can be possibly eliminated through slurry wall and optimized recovery system at Site MP, the existing solvent plume will be diminished in a short period, i.e. 5 to 10 years time frame. An interim remediation system will be installed at Site SS051 to reduce or eliminate that TCE source. Therefore, it becomes necessary to redo transport simulation based on a more appropriate source term estimate as model input. This section will present Phase 2 simulation results of six most feasible remediation options.

5.5.1 Incorporation of MP Zoom Model Parameters

Following changes were made to incorporate the MP zoom model input and output to Zone 4 off-base model packages for Phase 2 transport simulation:

- Source term: Table 5-6 lists revised source terms for model input. The decreasing source term was made based on evaluation of Phase 1 off-base and MP zoom model simulations, and consultation with Kelly AFB personnel. Concentration levels at initial two years are within ranges of the maximum concentrations detected in the monitoring wells in areas of the plume sources. The decaying source terms are supported by recent monitoring data that show a continually decreasing trend. The source terms were placed in the same cells as Phase 1 simulation in Figure 5-1.

Table 5-6
Revised Source Terms for Phase 2 Transport Simulation

Stress Period	Time (years)	MP Source	Time (years)	SS051 Source
		PCE (ppb)		TCE (ppb)
1	2	1000	2	200
2	2	100	2	100
3	6	20	2	50

- Initial concentrations: Existing plume concentrations at Site MP depicted on Figures A-4 and A-5 were loaded on input concentration files of total plumes documented in Section 5.3.2.

- Biodegradation rate: Site MP degradation half-lives of 4 years, 4 years, 3 years, and 2 years for PCE, TCE, DCE, and VC, respectively, were inserted into the updated Zone 4 off-base zoom model.

- Slurry wall: The slurry wall was represented with a MODFLOW horizontal flow barrier package.

- Low K block: the low K block varying from 5 to 100 ft/day in the Site MP area was placed in the Zone 4 off-base model K-field.

5.5.2 Simulation Results of the Most Feasible Remediation Options (Phase 2)

The Phase 2 transport simulations of each most feasible remediation option were run for 25 years. Results are summarized using plots of concentration distributions at 5-year time intervals starting at 0 year and ending at 25 years (Figure 5-52 through Figure 5-69). At years 25, plume concentration levels of PCE, TCE, DCE, and VC are all below its individual MCLs. The concentration plots show the area enclosed by the MCL levels of 5 ppb, 5 ppb, and 2 ppb for PCE, TCE, and VC, respectively. Concentration plots of DCE are not shown because model results indicate that the DCE concentration is below its MCL at all time intervals.

A summary table was prepared to show the remaining area still above MCLs in percentage of the existing plume at initial conditions for each compound at 5-year intervals for the entire 25-year simulation (Table 5-7). The contaminant area was separated to East Kelly and off-base. A pie chart showing the percentage of remaining contaminated area off-base in black was inserted into the corresponding 5-year concentration plots. Figure 5-70 presents a bar chart breaking down a four 5-year segment to show percentage of area remaining TCE contaminated off-base. Figures 5-71 through 5-76 show the change in the maximum concentration of PCE, TCE, and VC over time for the portions of the plume on East Kelly and off-base. Table 5-8 summarizes the time (years) at which the maximum concentration has dropped below its MCLs for all remediation options.

The following observations of Phase 2 simulation are made:

- In East Kelly, rapid reduction for PCE, TCE, and VC was obtained for all remediation options at the first 10 years of simulation. Time ranges for achieving MCLs are 5 to 10 years for VC, 10 to 15 years for PCE, and 15 years for TCE.

- For off-base plume, rapid reduction was obtained for TCE at first 5 years, and was tailed off after 5 years. A rather gradually decreasing pattern is shown for PCE and VC. By years 15, 95% plume is gone except for VC generated from degradation. MCLs are achieved for PCE and TCE at years 25, and for VC at years 10 to 20.

In terms of plume reduction, no significant variance exists among each remediation option. Because of their widespread well placement, Options A1 and C1 appear most effective in years 5 to 10. After 10 years, all options are essentially identical.

Table 5-7
Area Remaining Contaminated in Acre and Percentage
(the Most Feasable Options – Phase 2)

	Option D		Option B		Option F		Option A1		Option C1		Option E1	
Years	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent	Acre	Percent
PCE, Off Base												
0	4158		4158		4158		4158		4158		4158	
5	1457	35.0%	1327	31.9%	1234	29.7%	987	23.7%	987	23.7%	1277	30.7%
10	330	7.9%	262	6.3%	238	5.7%	154	3.7%	154	3.7%	253	6.1%
15	60	1.4%	54	1.3%	60	1.4%	50	1.2%	50	1.2%	60	1.4%
20	14	0.3%	14	0.3%	14	0.3%	14	0.3%	14	0.3%	14	0.3%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
PCE, East Kelly												
0	179		179		179		179		179		179	
5	9	4.9%	11	6.2%	9	4.8%	5	2.7%	5	2.7%	8	4.4%
10	0	0.0%	1	0.5%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
15	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
20	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
TCE, Off Base												
0	3897		3897		3897		3897		3897		3897	
5	2808	72.1%	2372	60.9%	2191	56.2%	1681	43.1%	1627	41.7%	2352	60.3%
10	1615	41.4%	857	22.0%	745	19.1%	380	9.7%	390	10.0%	806	20.7%
15	187	4.8%	92	2.4%	55	1.4%	41	1.0%	50	1.3%	55	1.4%
20	21	0.5%	19	0.5%	21	0.5%	19	0.5%	19	0.5%	21	0.5%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
TCE, East Kelly												
0	318		318		318		318		318		318	
5	140	44.2%	169	53.2%	140	44.1%	146	46.0%	145	45.7%	139	43.9%
10	34	10.8%	32	10.2%	34	10.8%	20	6.3%	20	6.3%	34	10.8%
15	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
20	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
VC, Off Base												
0	32		32		32		32		32		32	
5	414	1292%	345	1076%	288	900.4%	103	321.5%	103	321.5%	327	1022%
10	290	906.5%	233	727.6%	92	288.2%	0	0.0%	0	0.0%	88	275.3%
15	21	64.5%	19	60.2%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
20	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
VC, East Kelly												
0	6		6		6		6		6		6	
5	0	0.0%	1	9.8%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
10	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
15	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
20	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%

Table 5-8
Time (years) for the Maximum Concentration to Reach the MCLs (Phase 2)

	PCE		TCE		VC	
Most Feasible	East Kelly	Off-base	East Kelly	Off-base	East Kelly	Off-base
Option A1	10	25	15	25	5	10
Option B	15	25	15	25	10	20
Option C1	10	25	15	25	5	10
Option D	10	25	15	25	5	20
Option E1	10	25	15	25	5	15
Option F	10	25	15	25	5	15

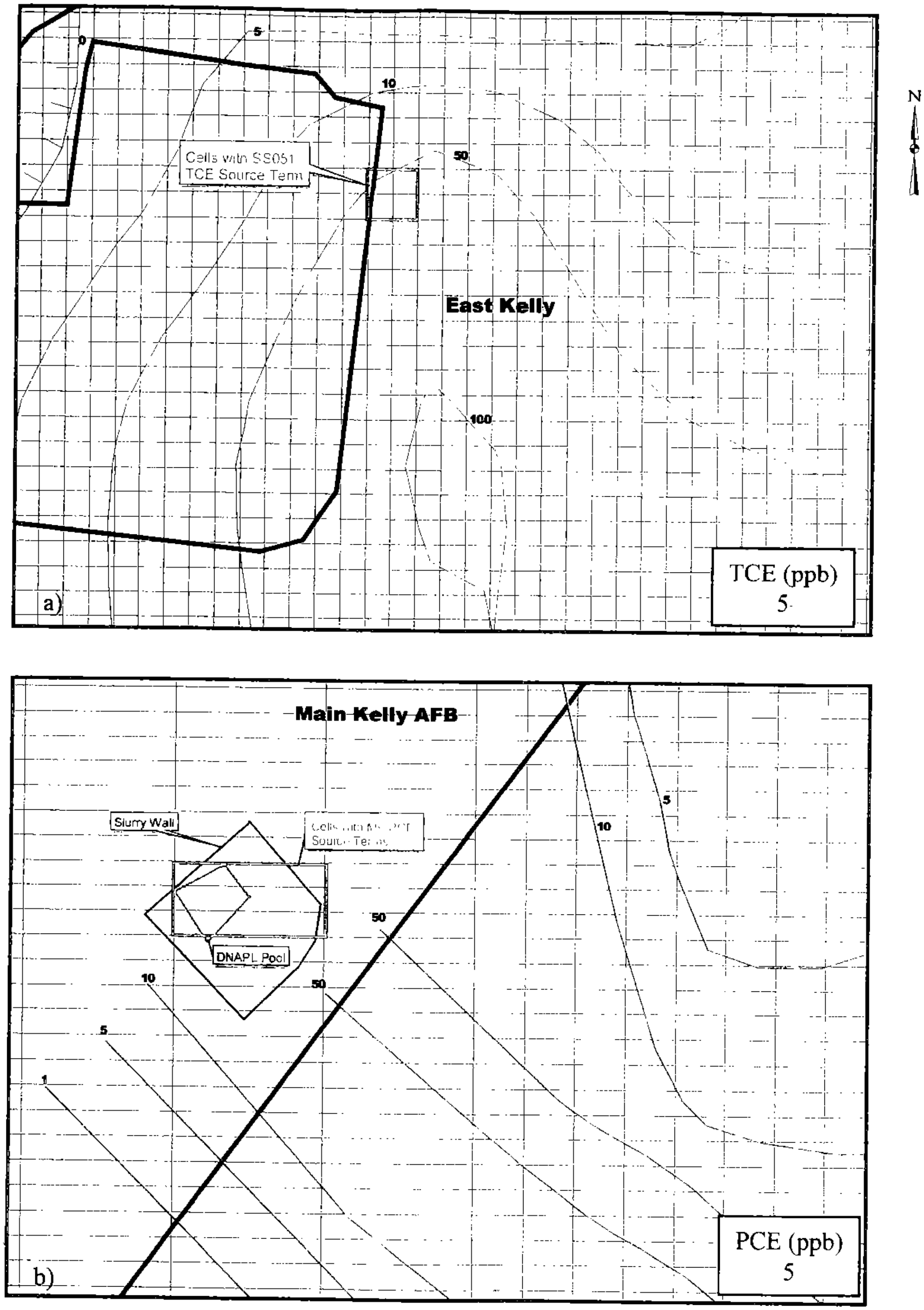


Figure 5-1 Source Term Cells at Site MP with PCE Contour (b) and Site SS051 with TCE Contour (a) on Zoomed-in View of the Zone 4 Model Domain

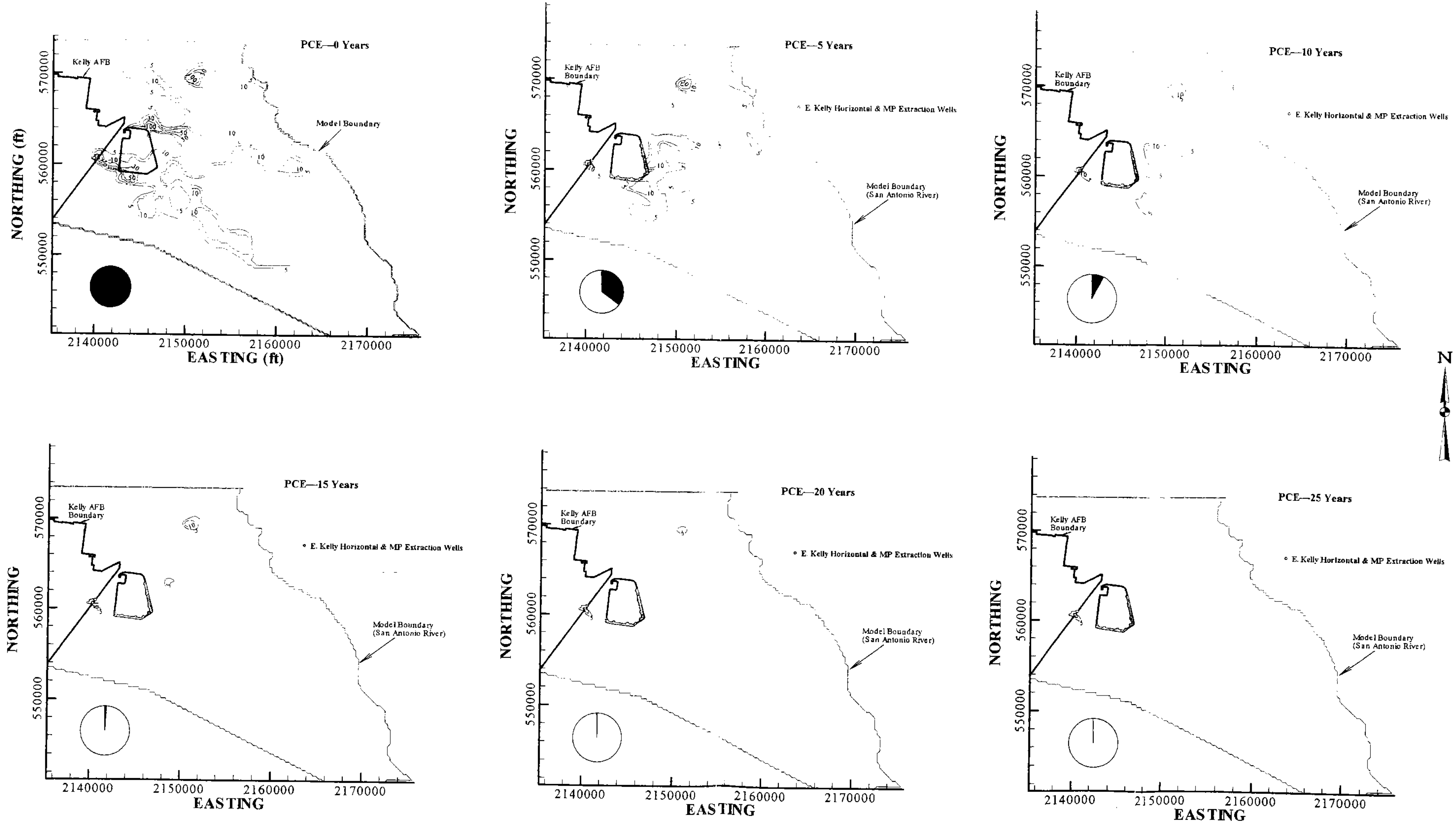


Figure 5-2 The Most Feasible Option D: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

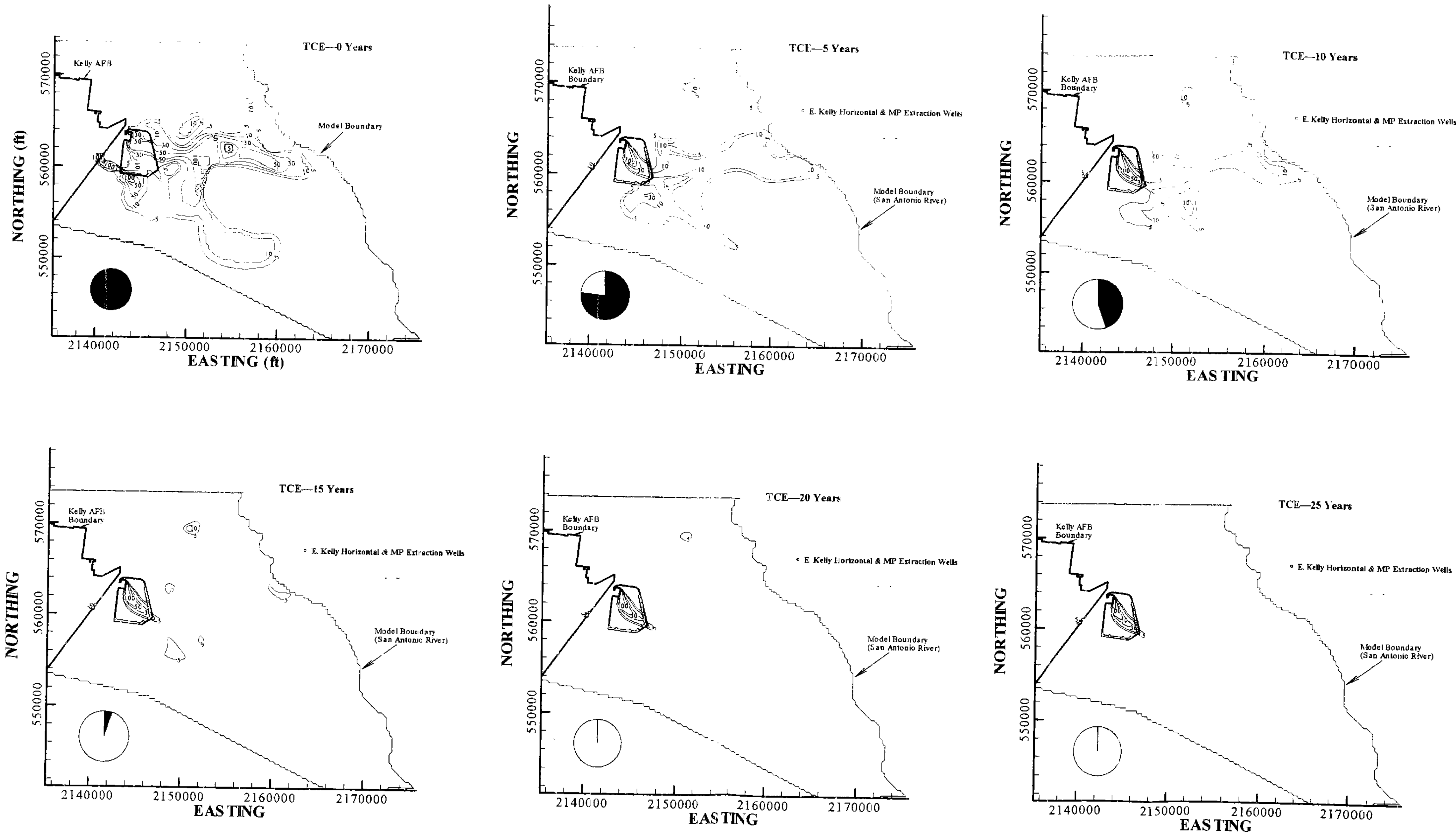


Figure 5-3 The Most Feasible Option D: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

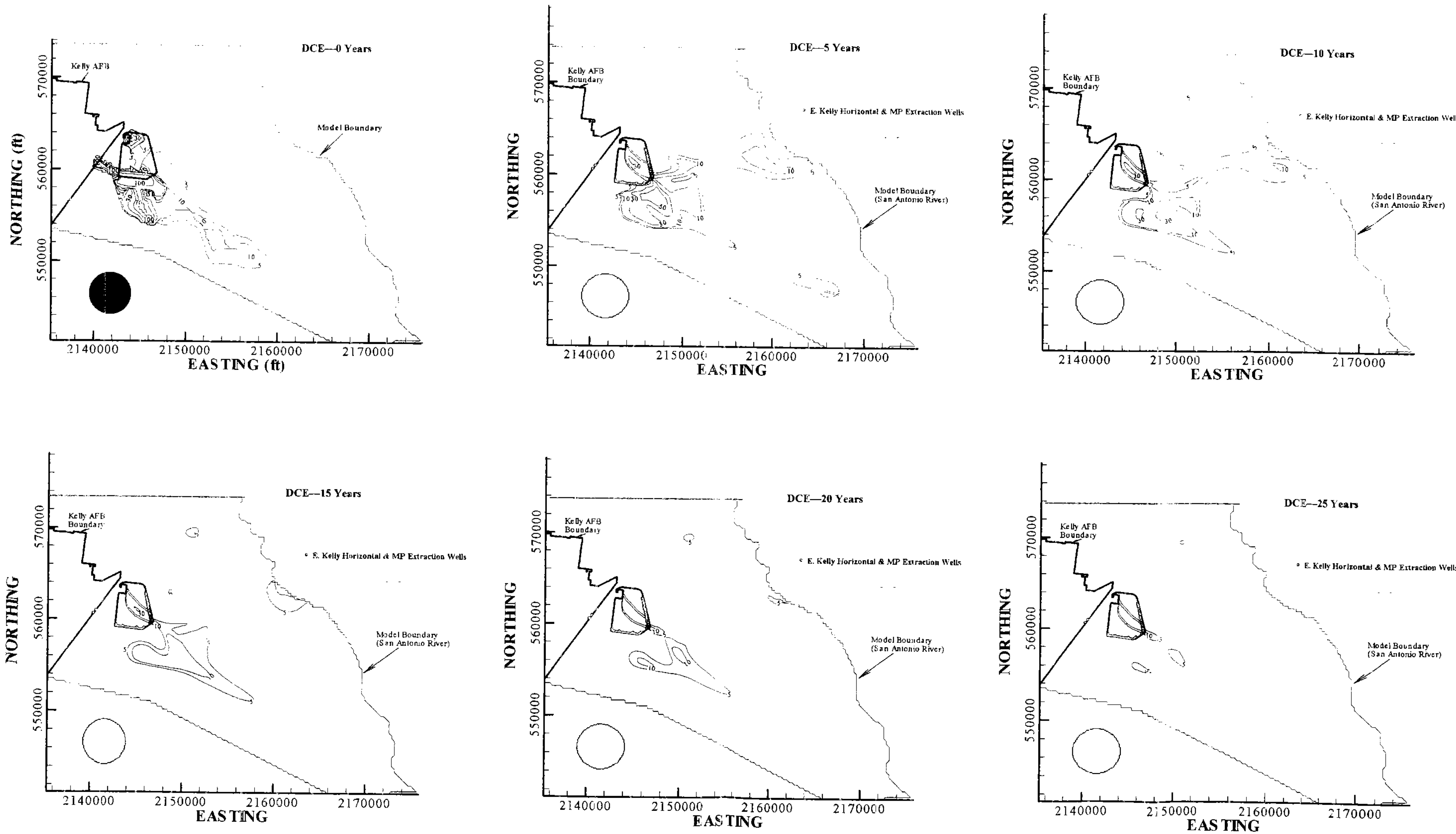


Figure 5-4 The Most Feasible Option D: Simulated DCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

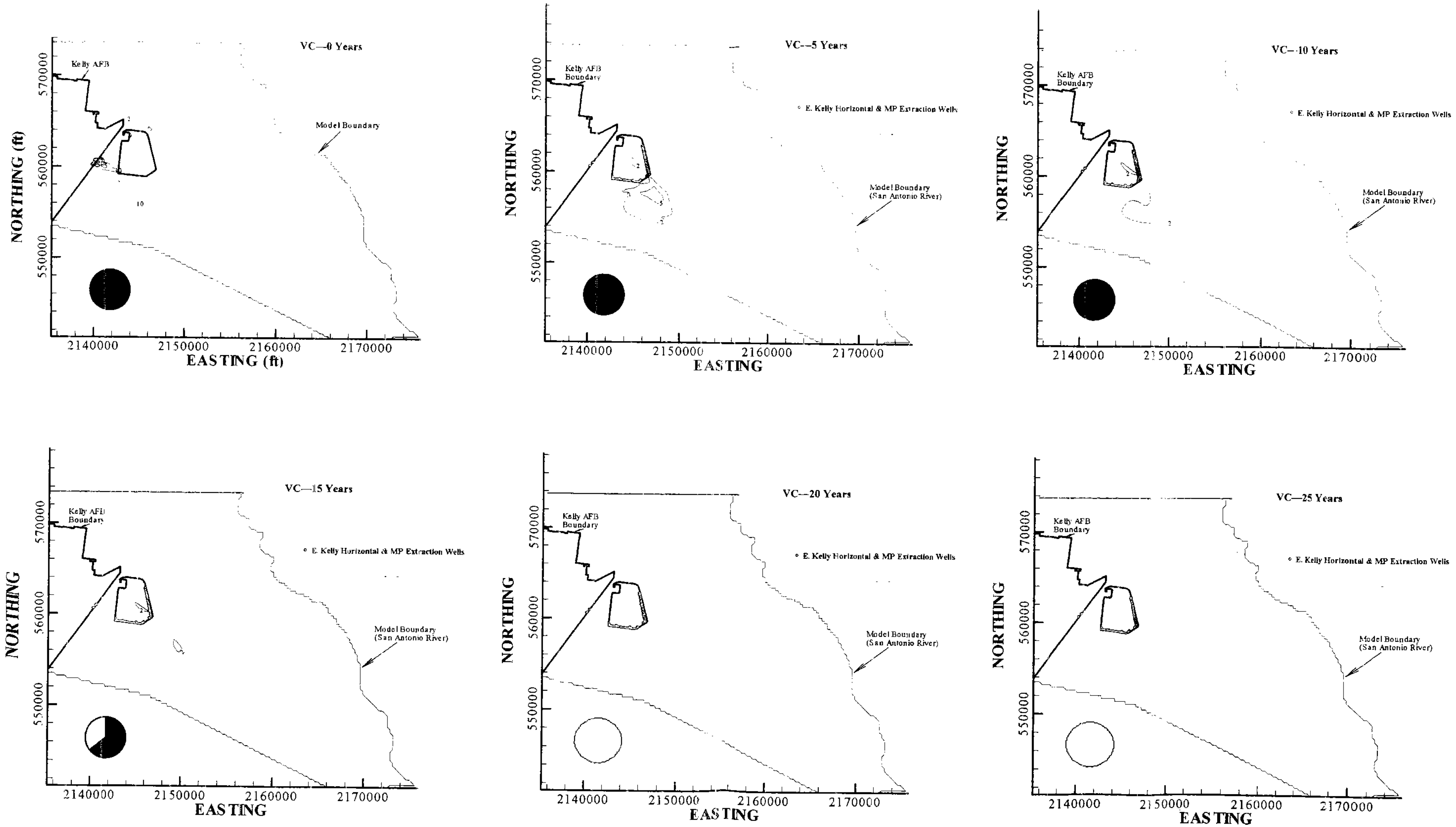


Figure 5-5 The Most Feasible Option D: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

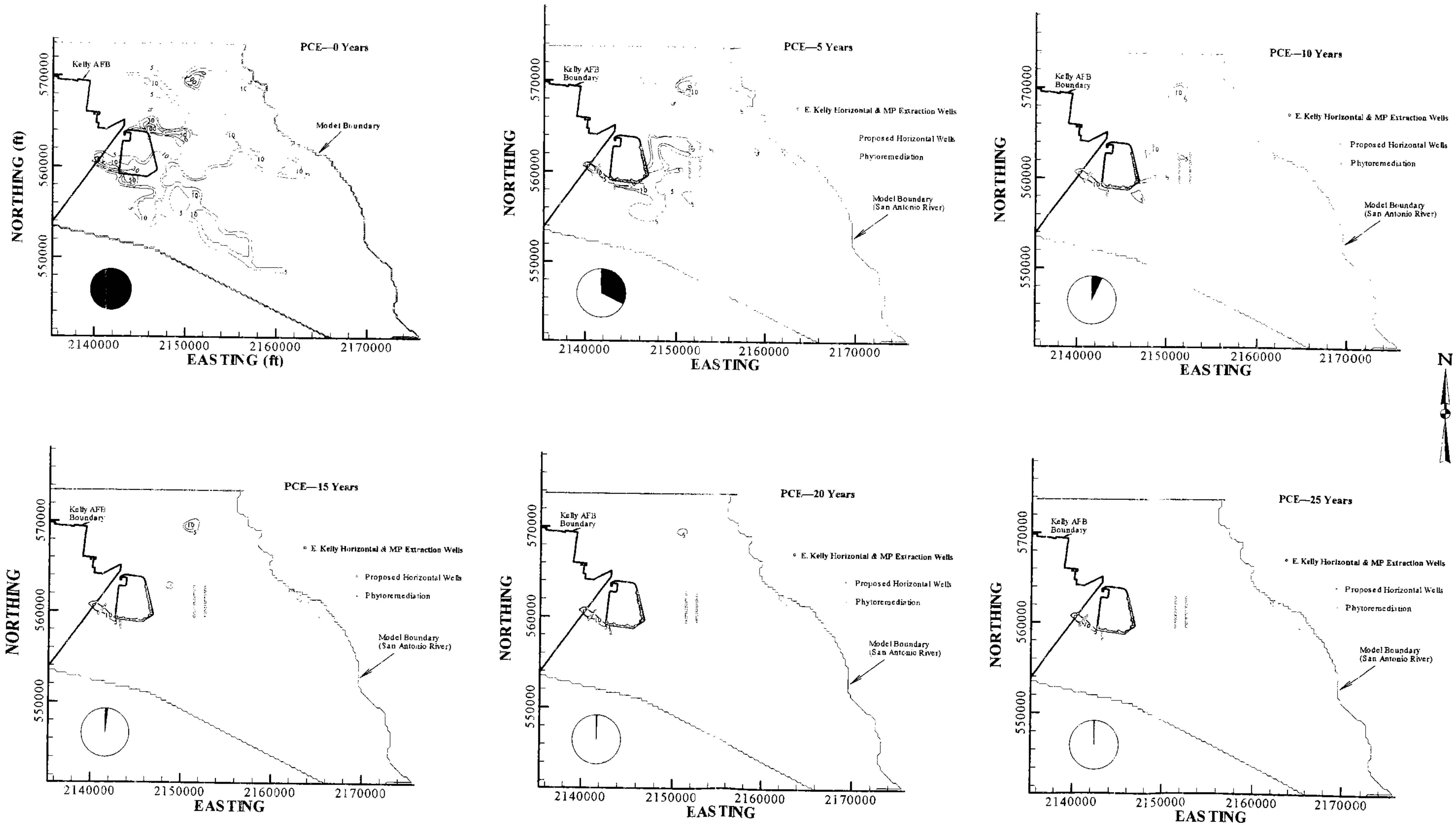


Figure 5-6 The Most Feasible Option B: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

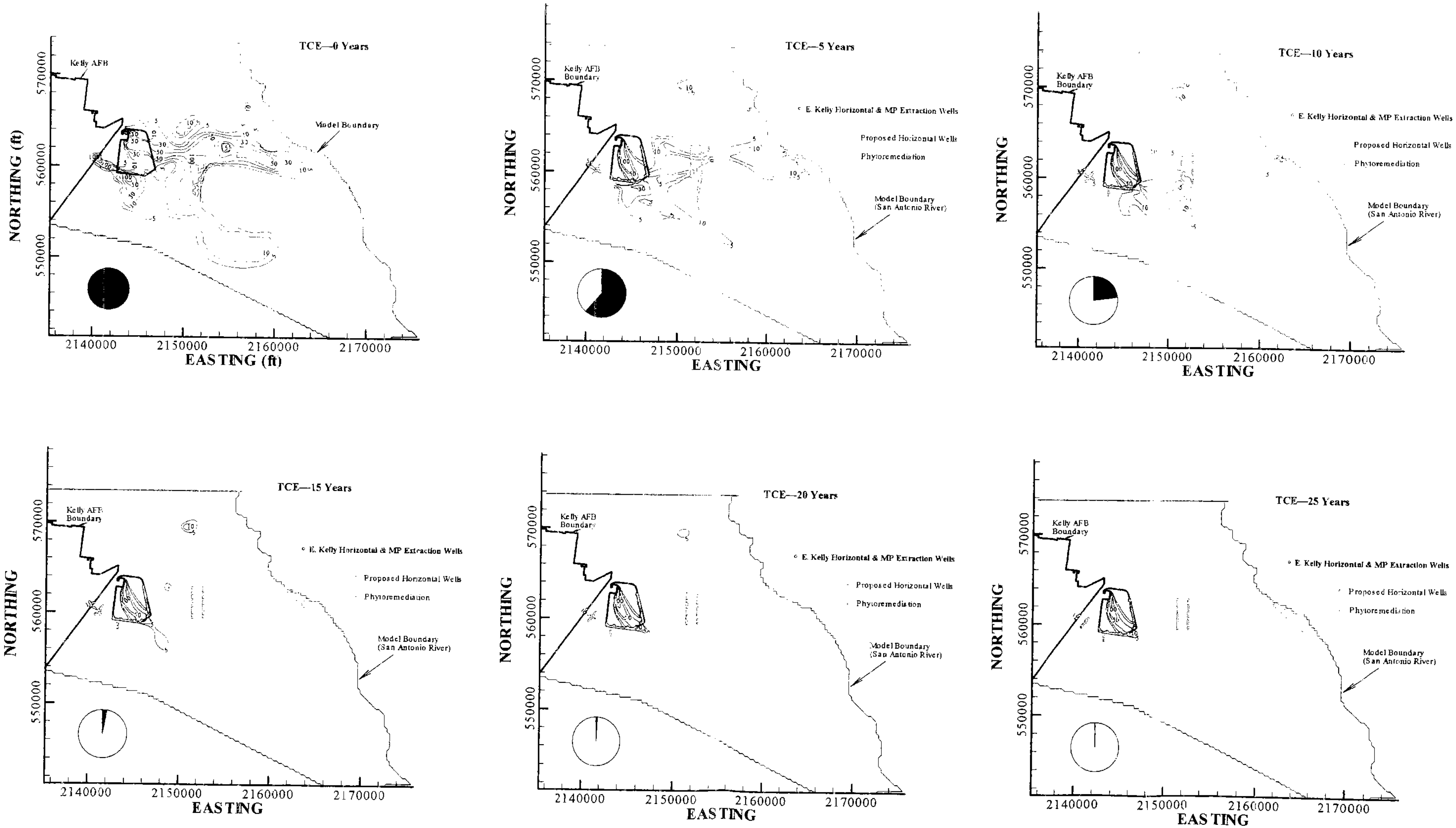


Figure 5-7 The Most Feasible Option B: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

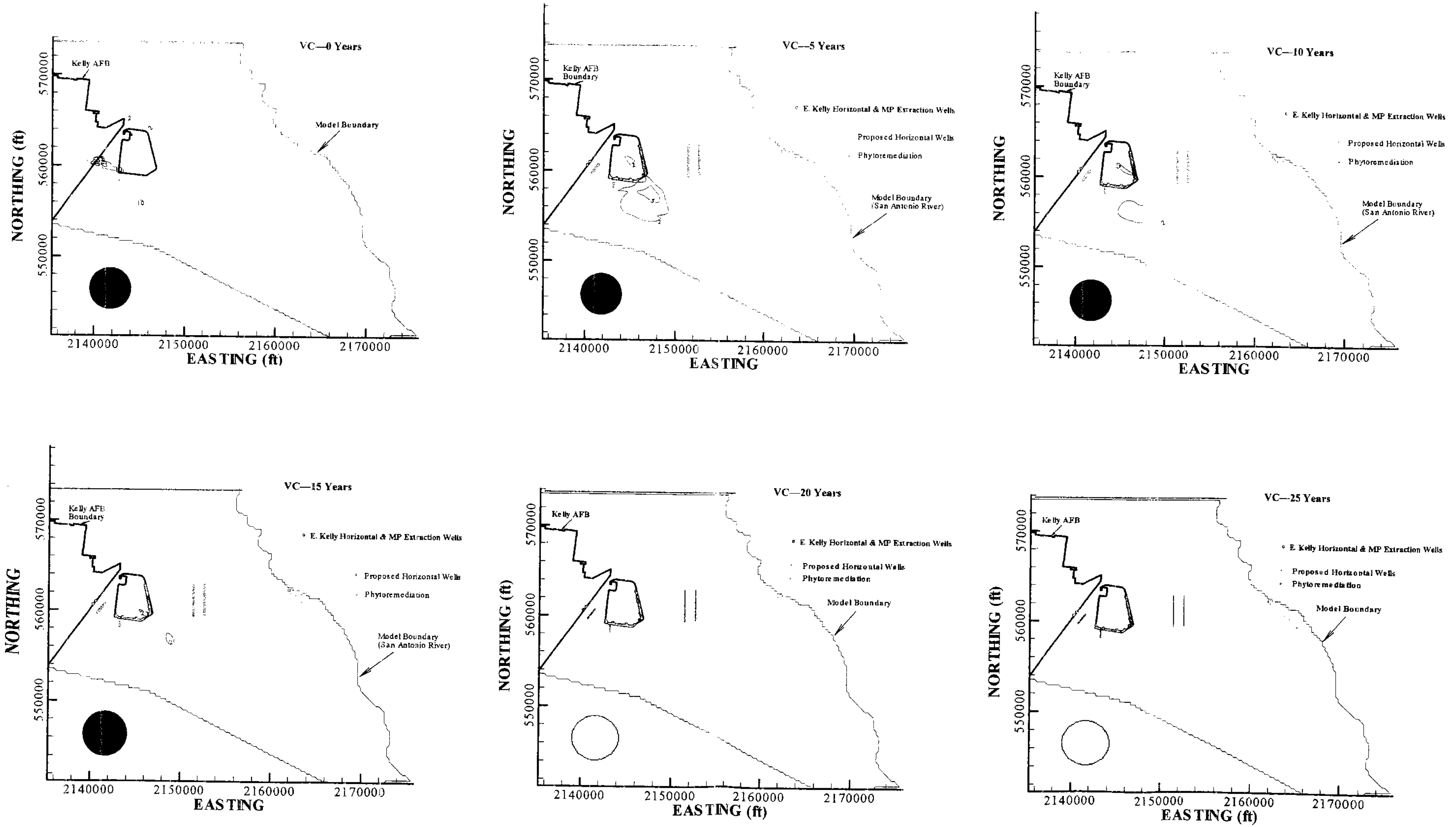


Figure 5-8 The Most Feasible Option B: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

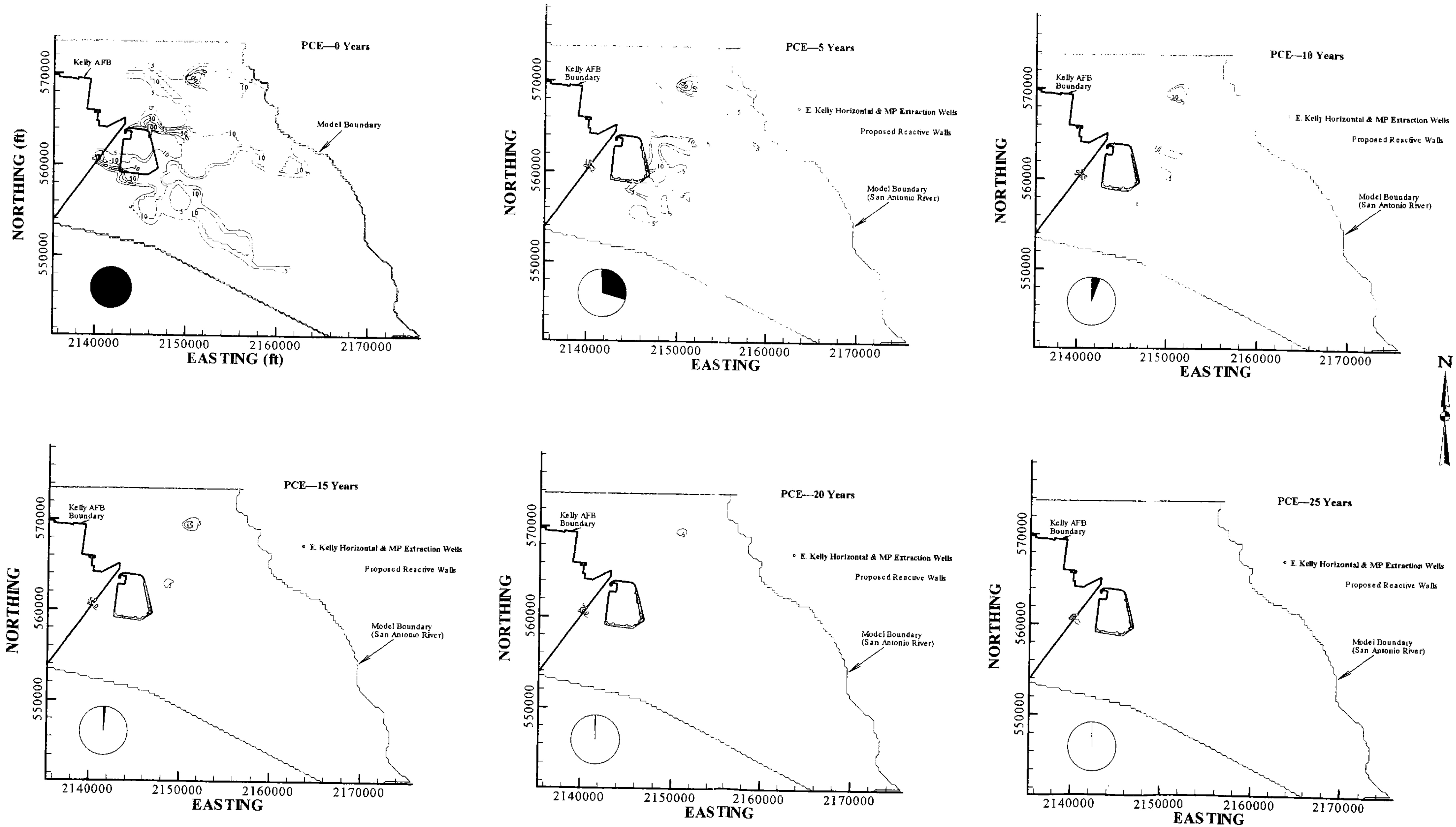


Figure 5-9 The Most Feasible Option F: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

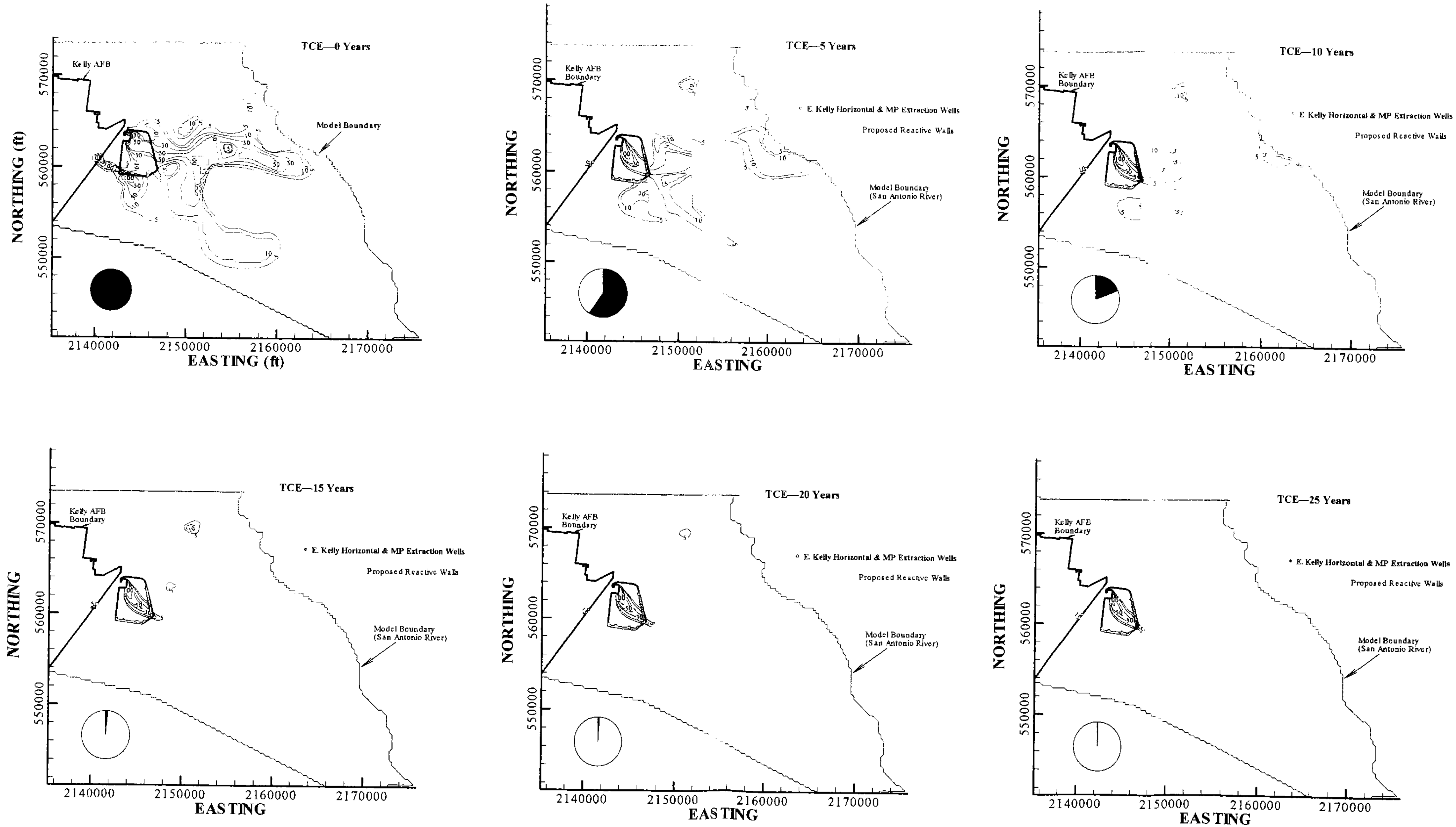


Figure 5-10 The Most Feasible Option F: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

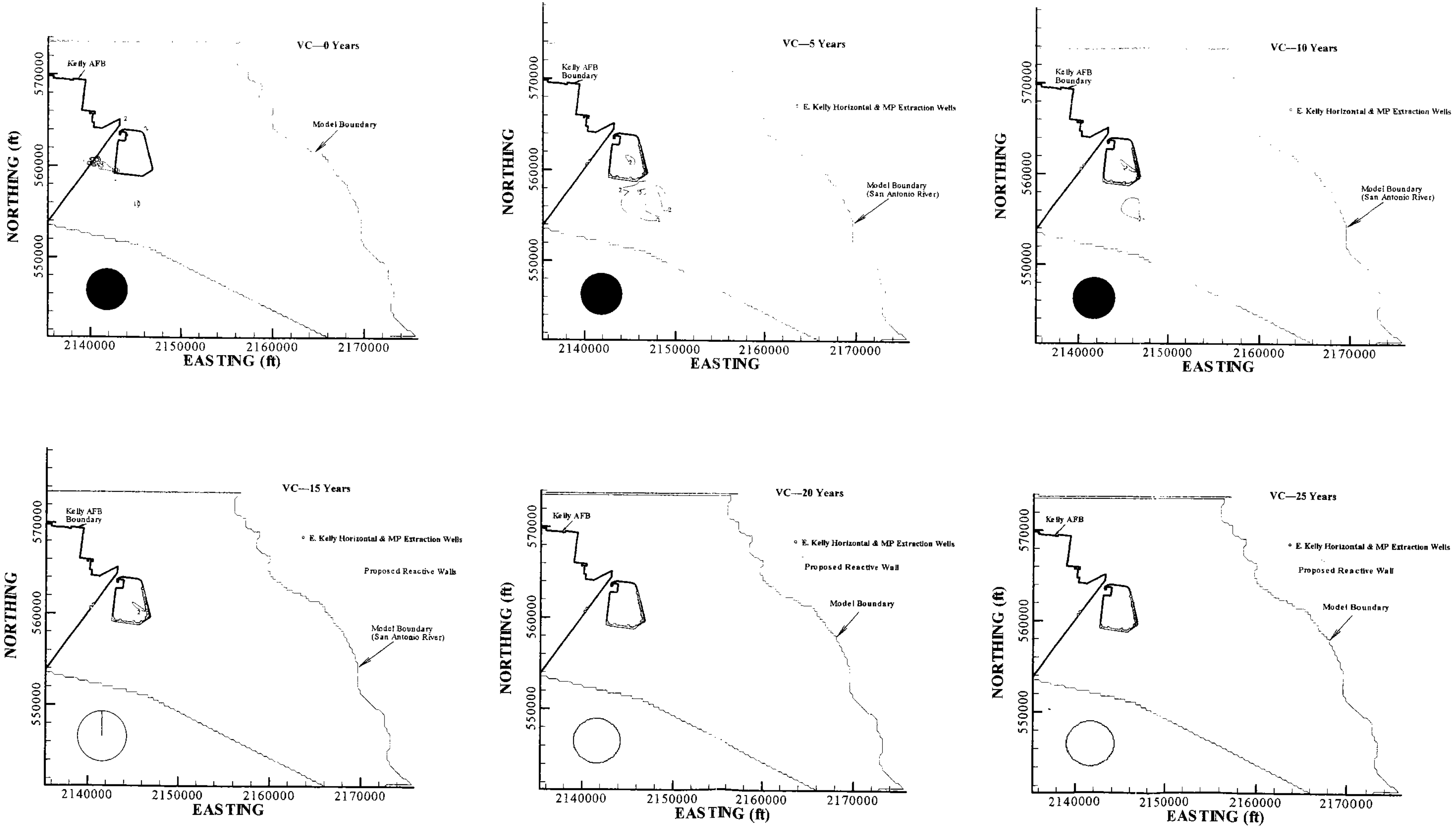


Figure 5-11 The Most Feasible Option F: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

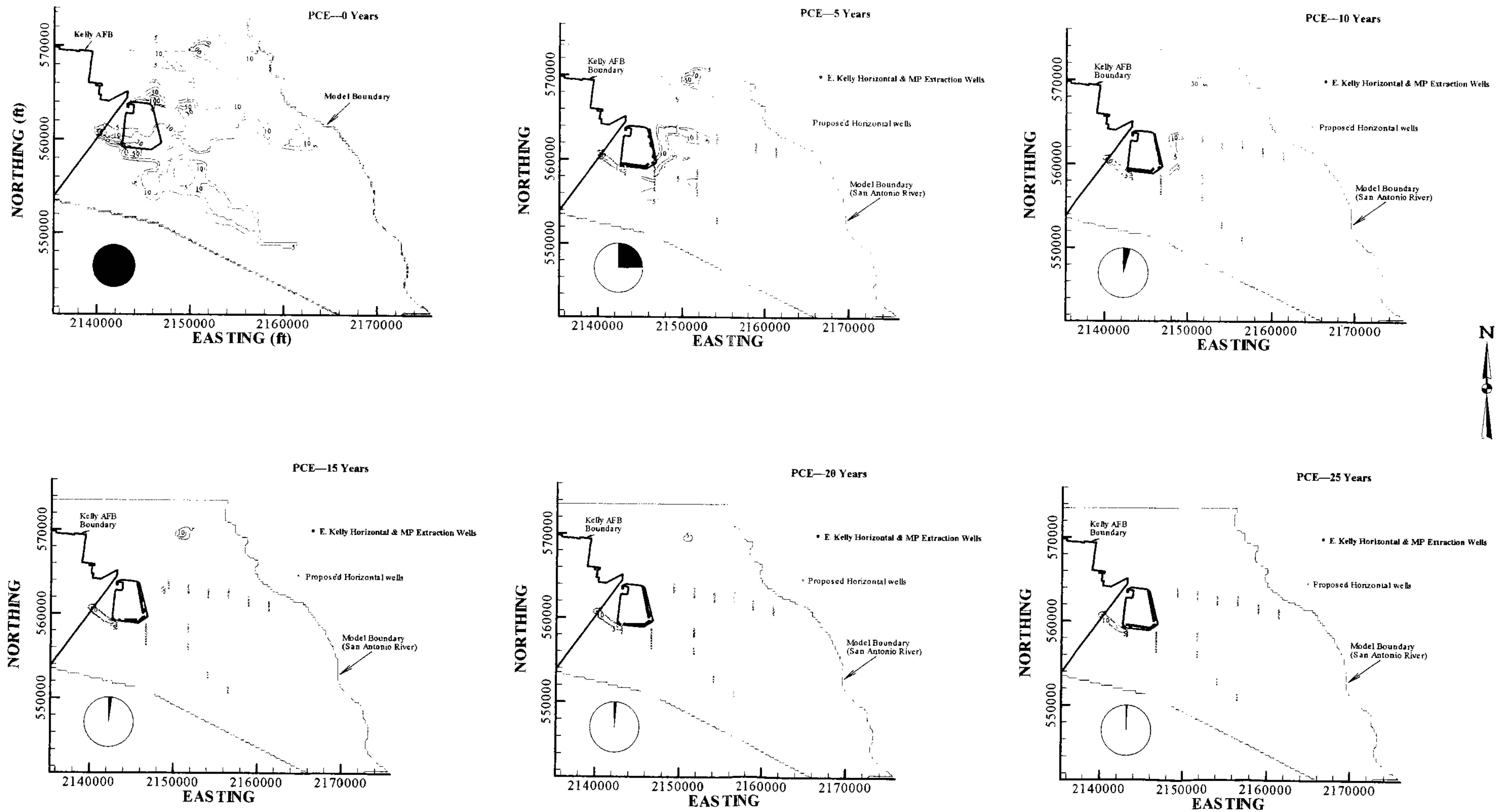


Figure 5-12 The Most Feasible Option A1: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

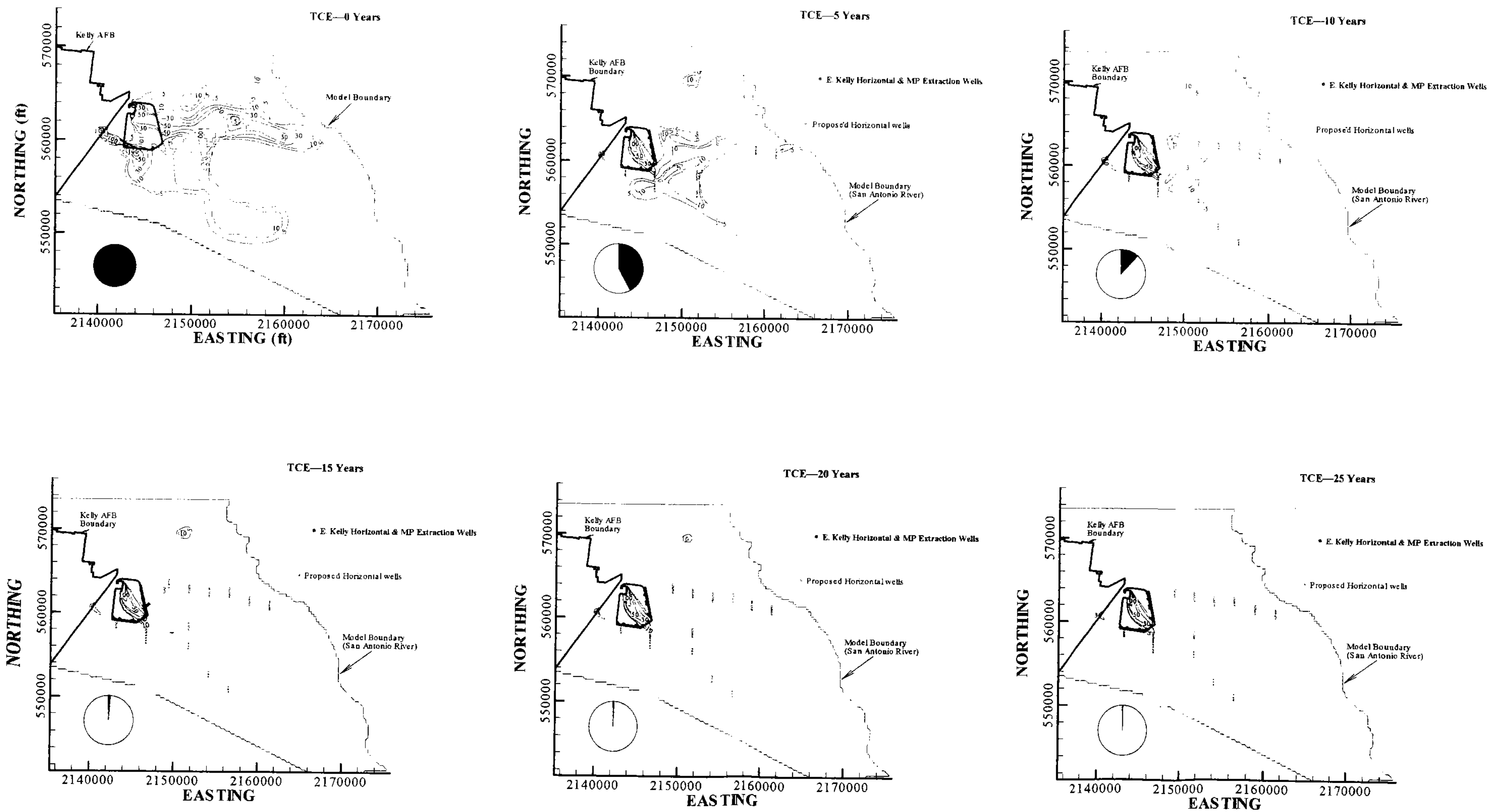


Figure 5-13 The Most Feasible Option A1: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

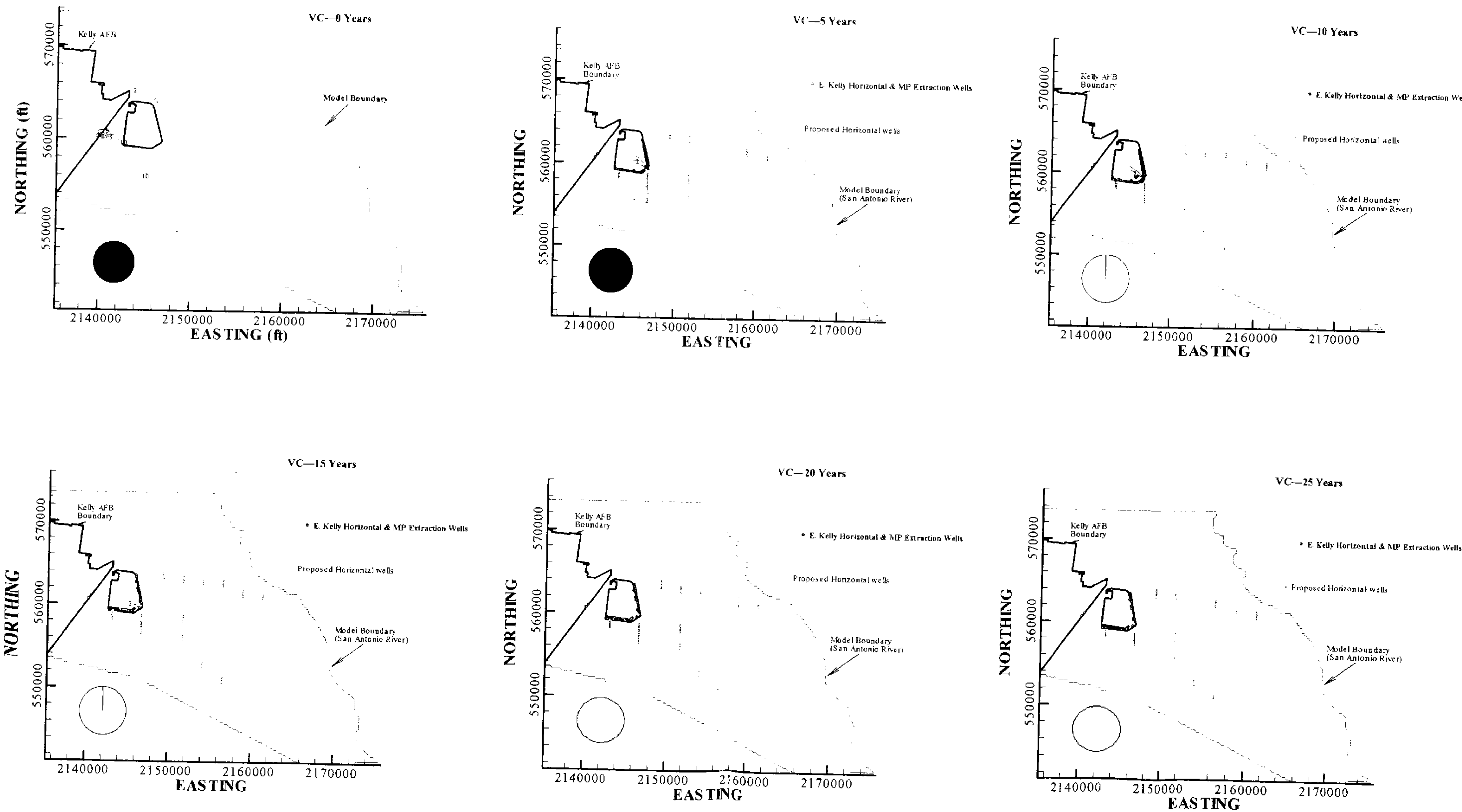


Figure 5-14 The Most Feasible Option A1: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

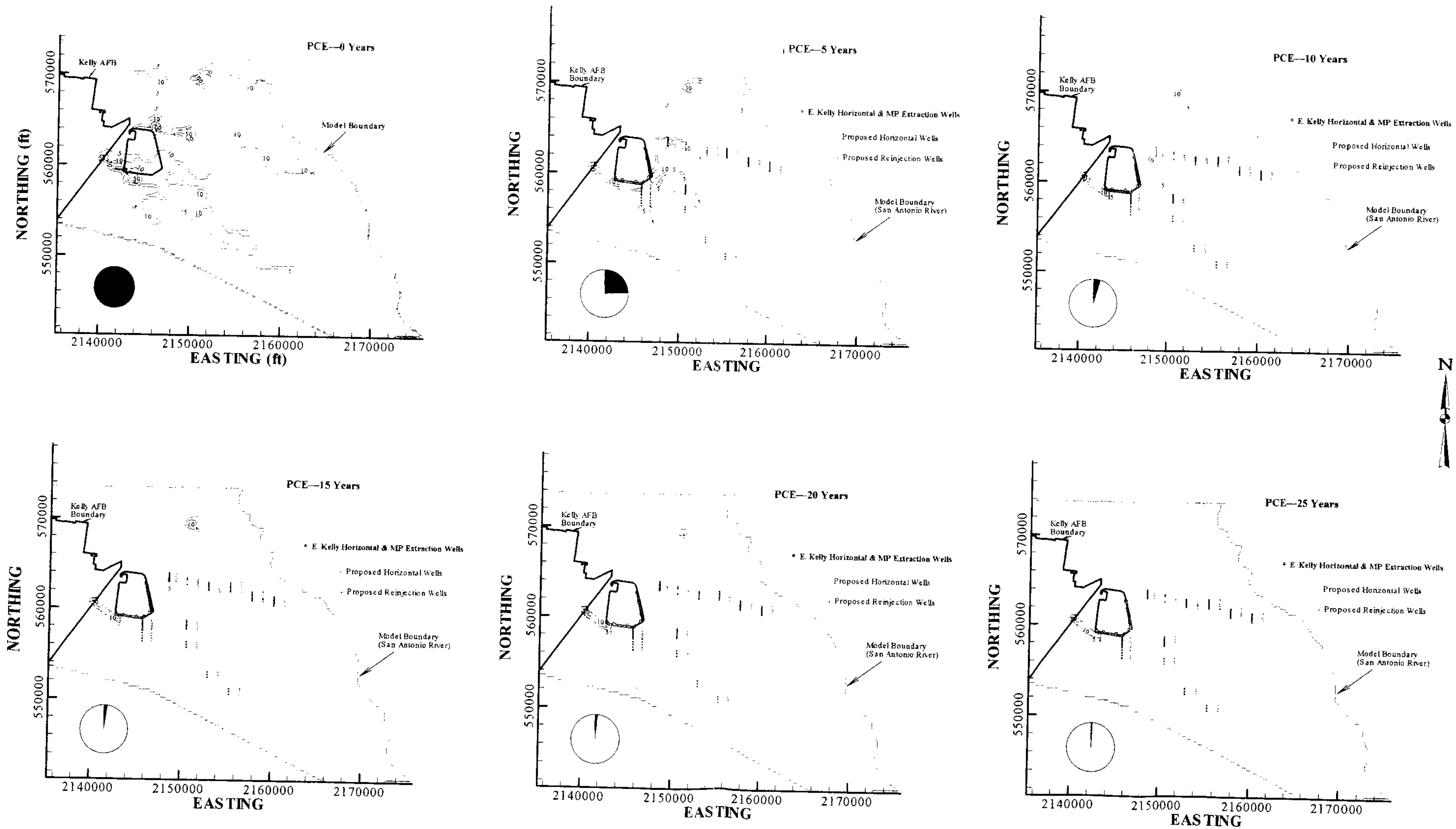


Figure 5-15 The Most Feasible Option C1: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

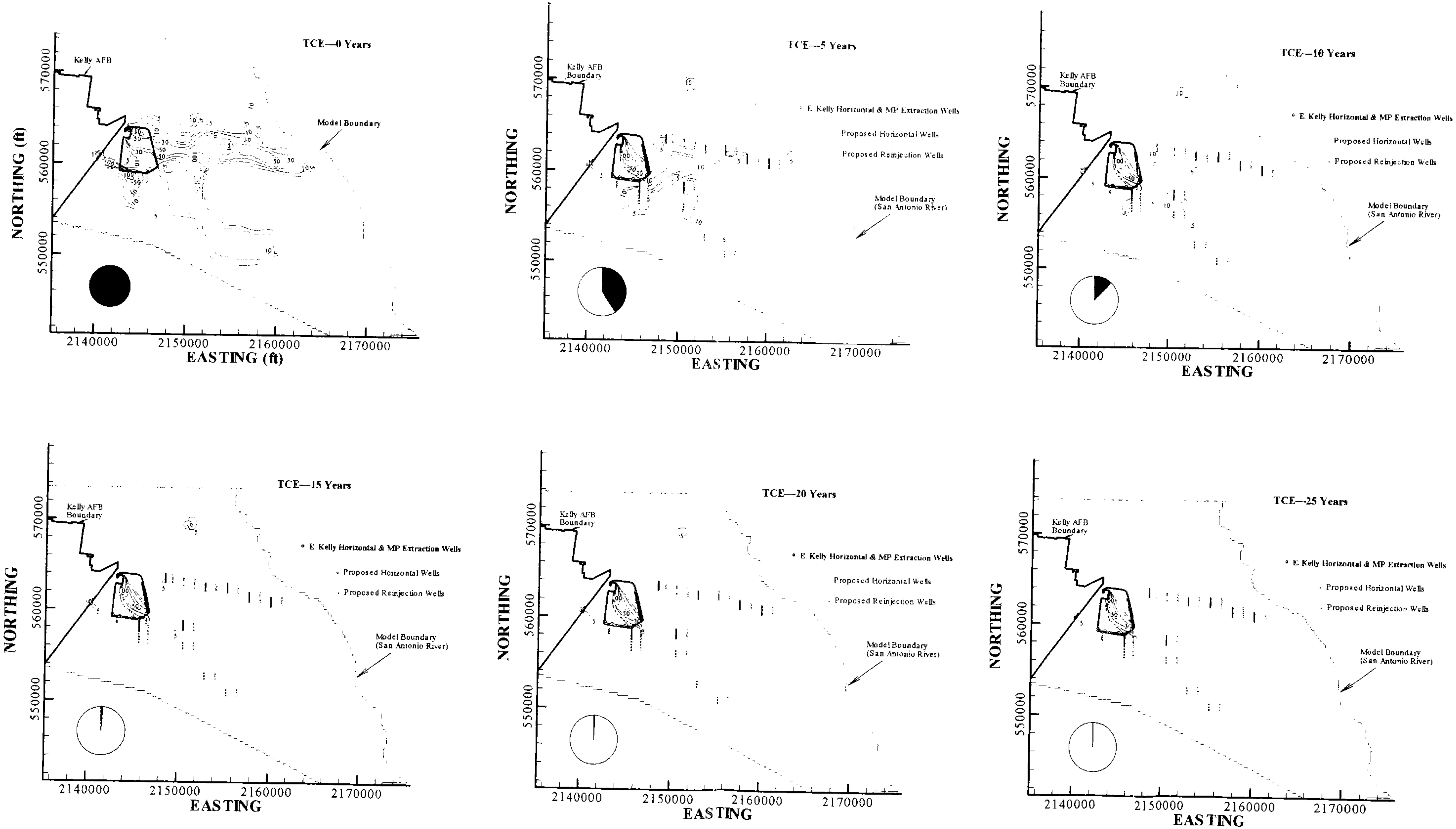


Figure 5-16 The Most Feasible Option C1: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

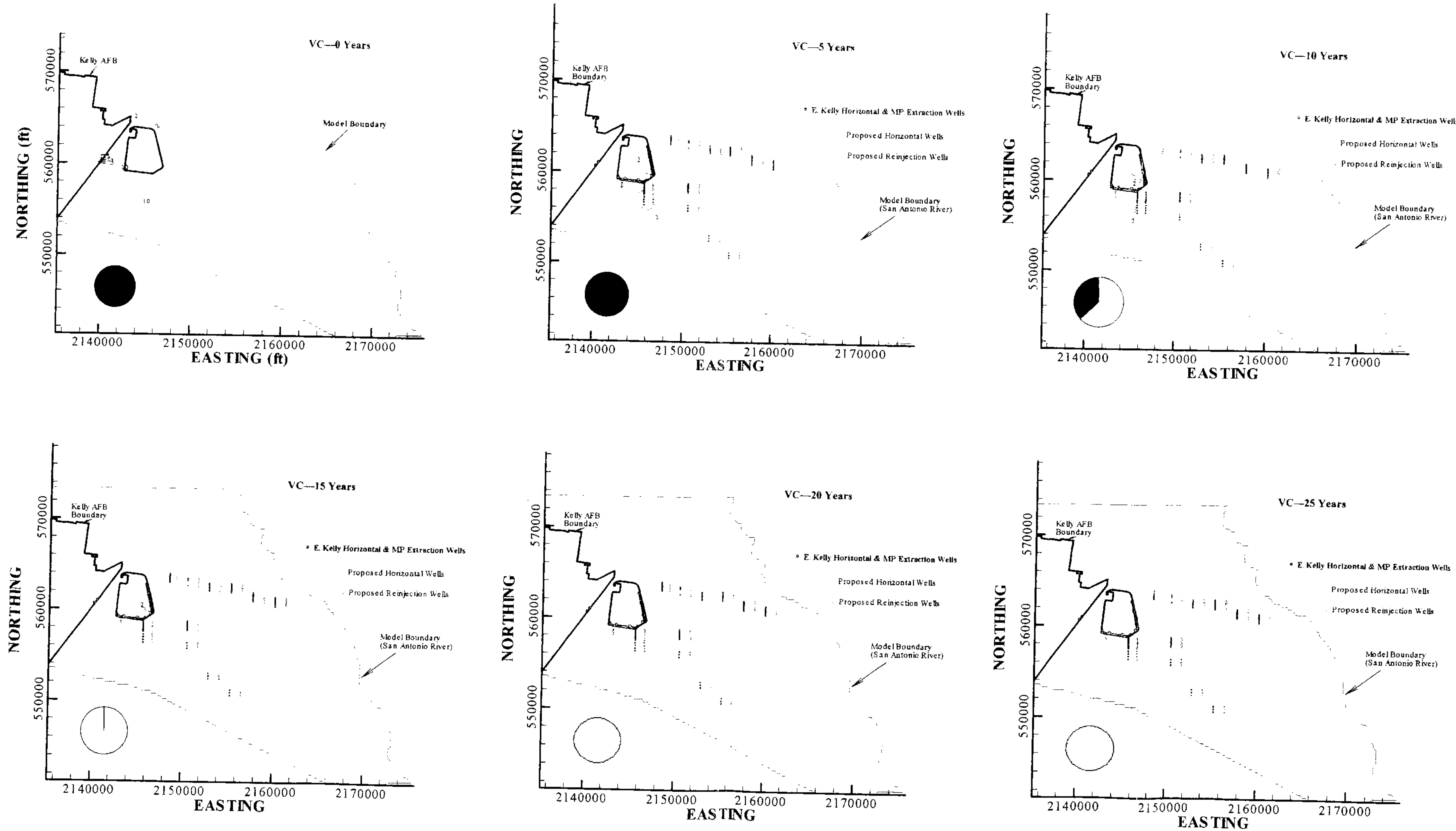


Figure 5-17 The Most Feasible Option C1: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

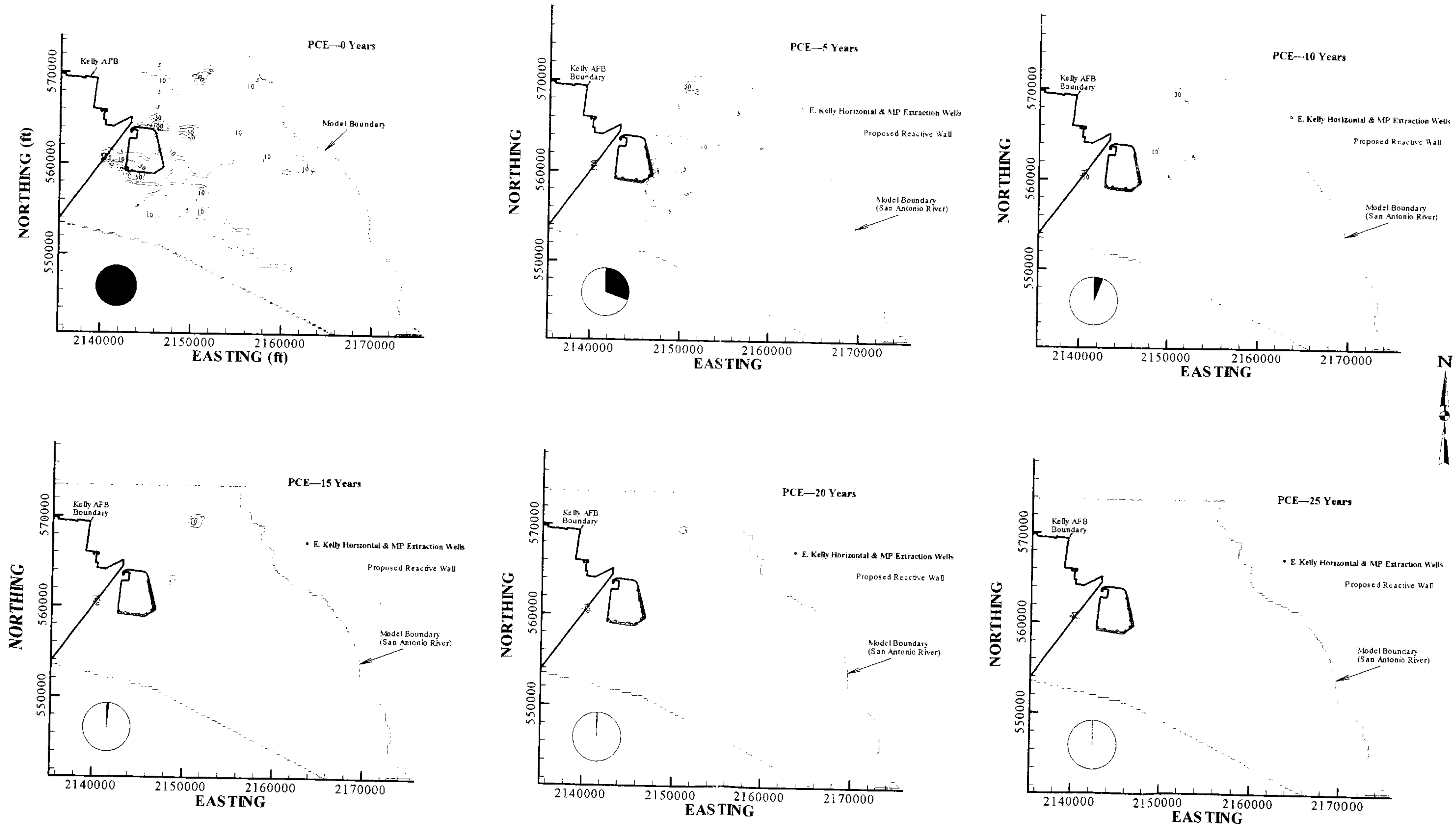


Figure 5-18 The Most Feasible Option E1: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

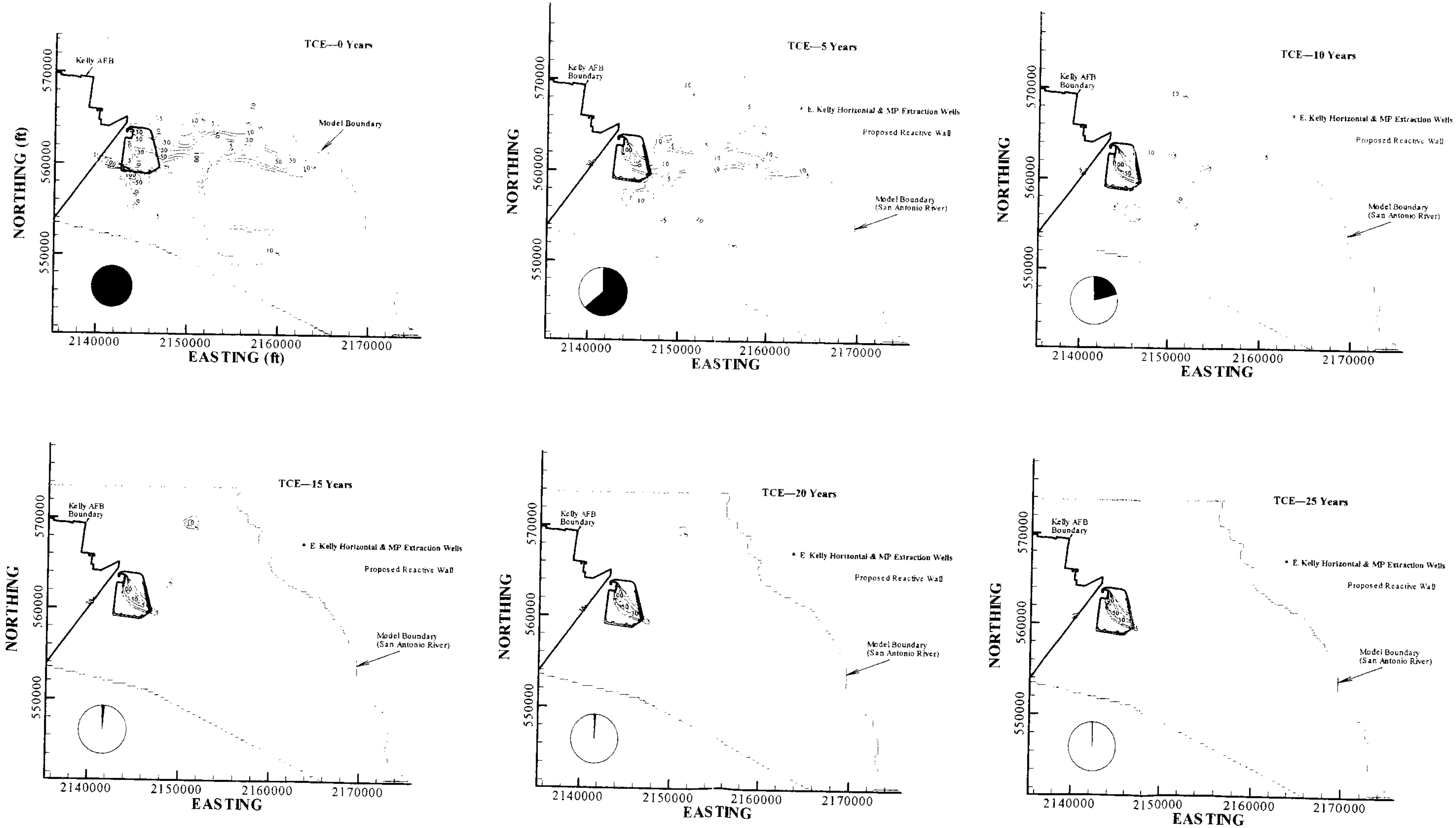


Figure 5-19 The Most Feasible Option E1: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

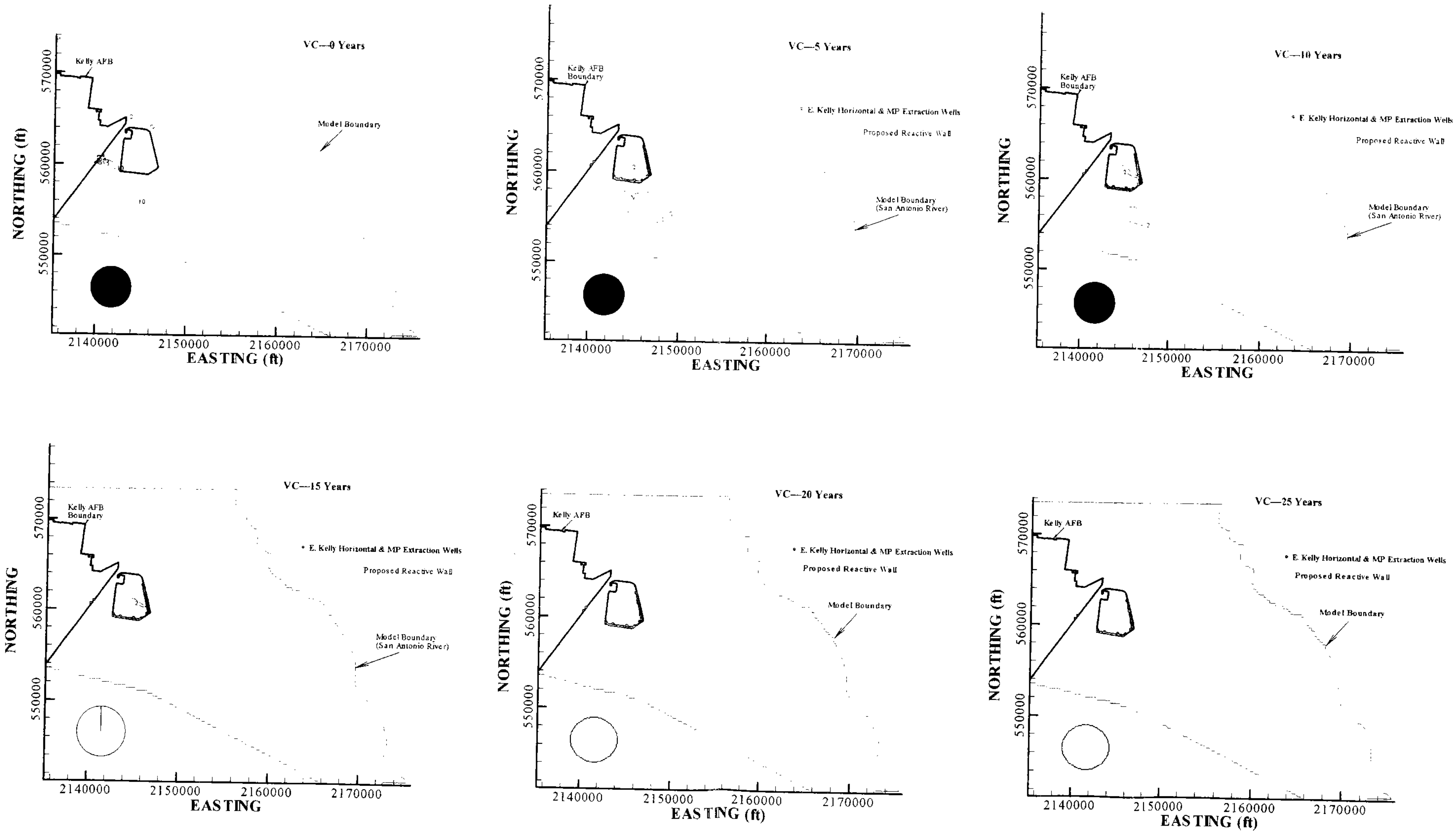


Figure 5-20 The Most Feasible Option E1: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

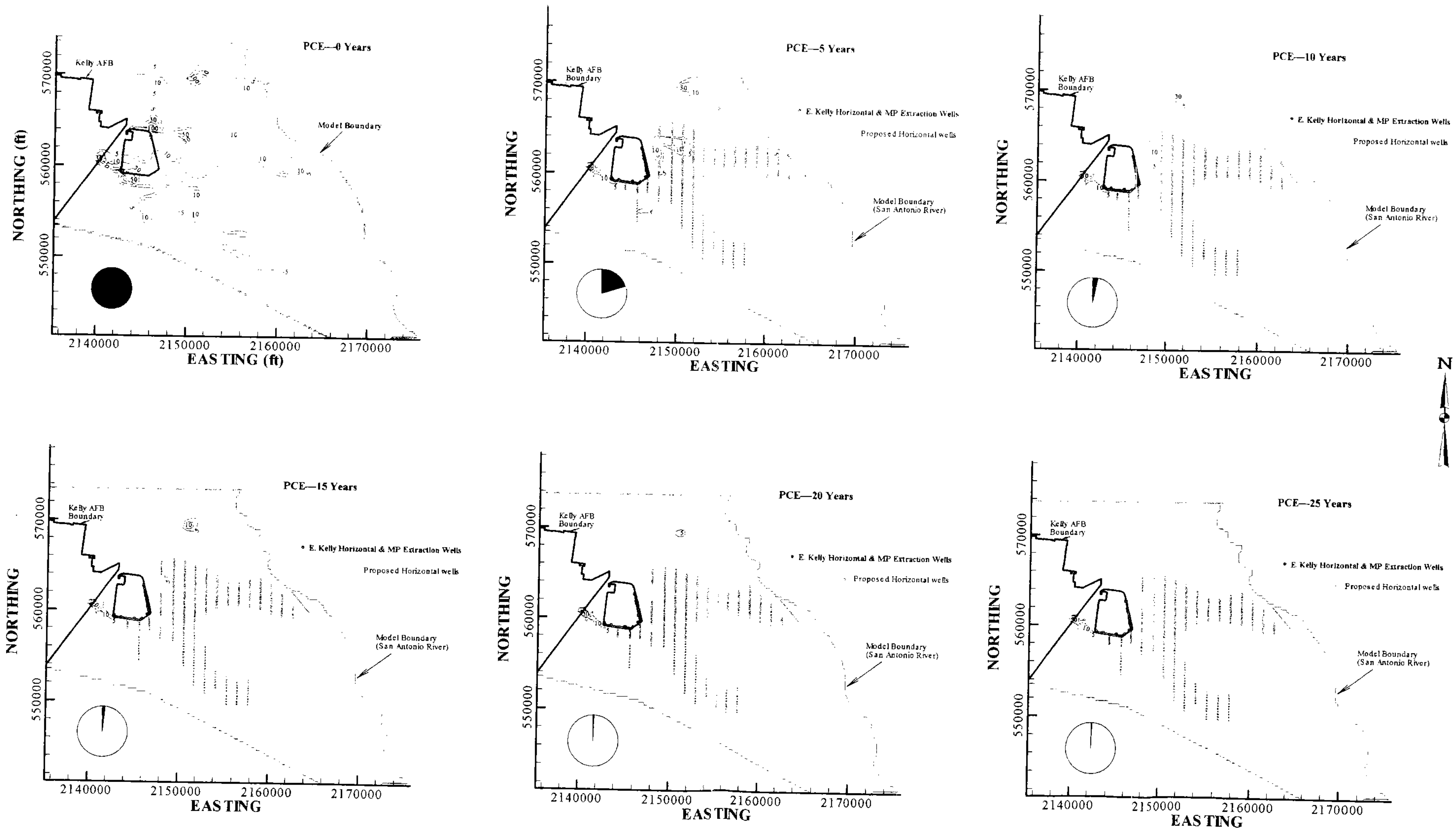


Figure 5-21 The Least Feasible Option A: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

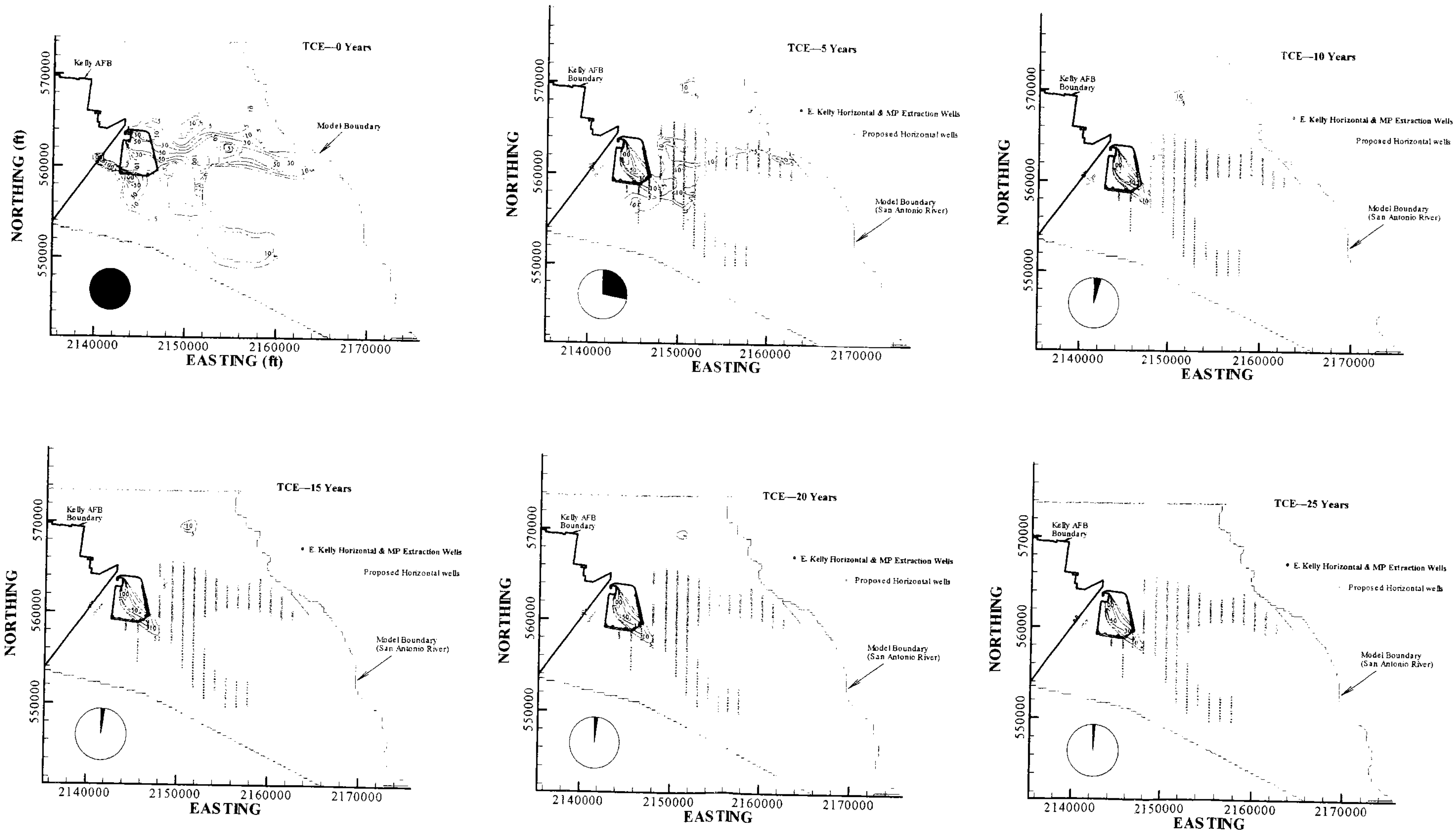


Figure 5-22 The Least Feasible Option A: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

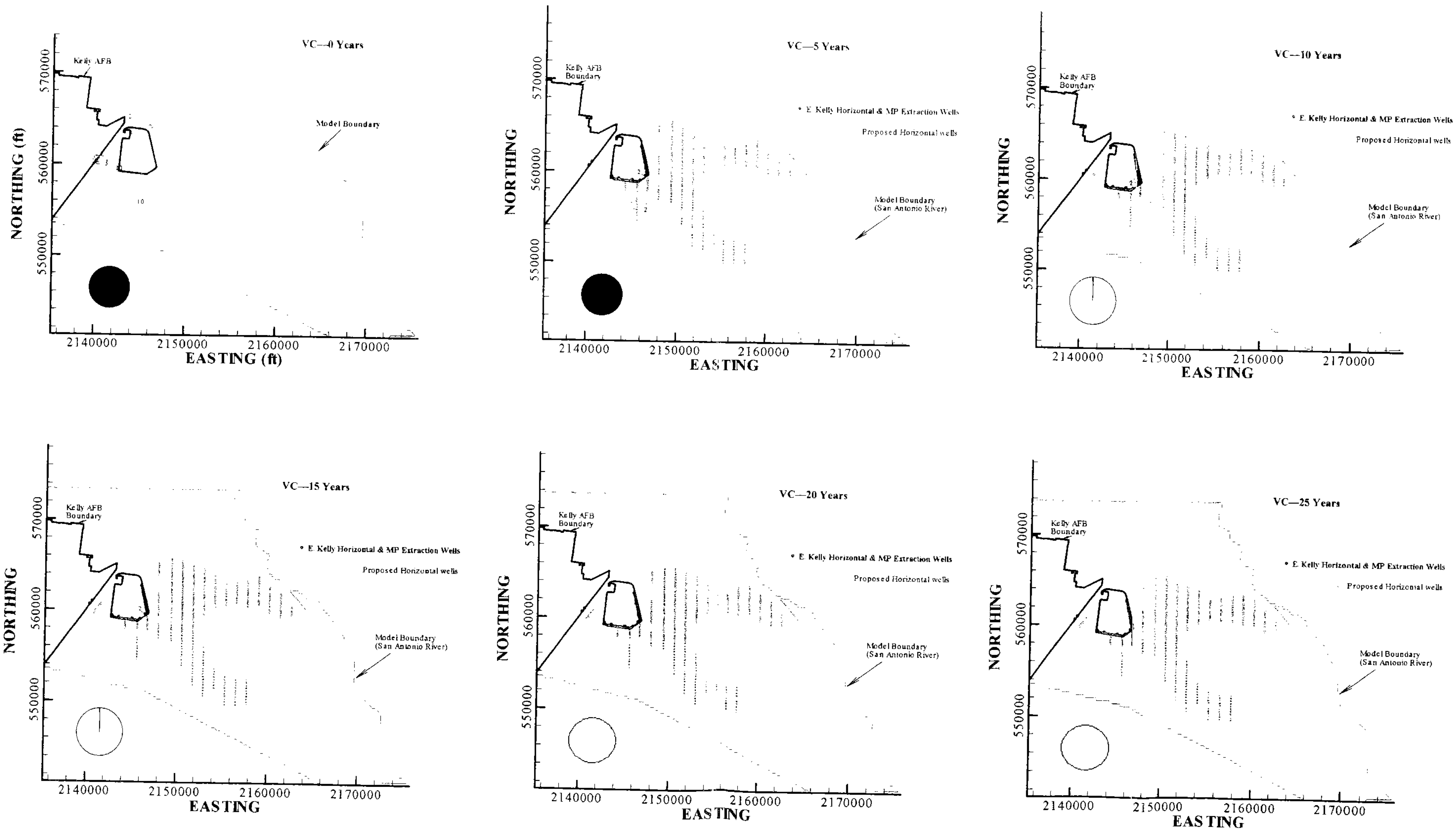


Figure 5-23 The Least Feasible Option A: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

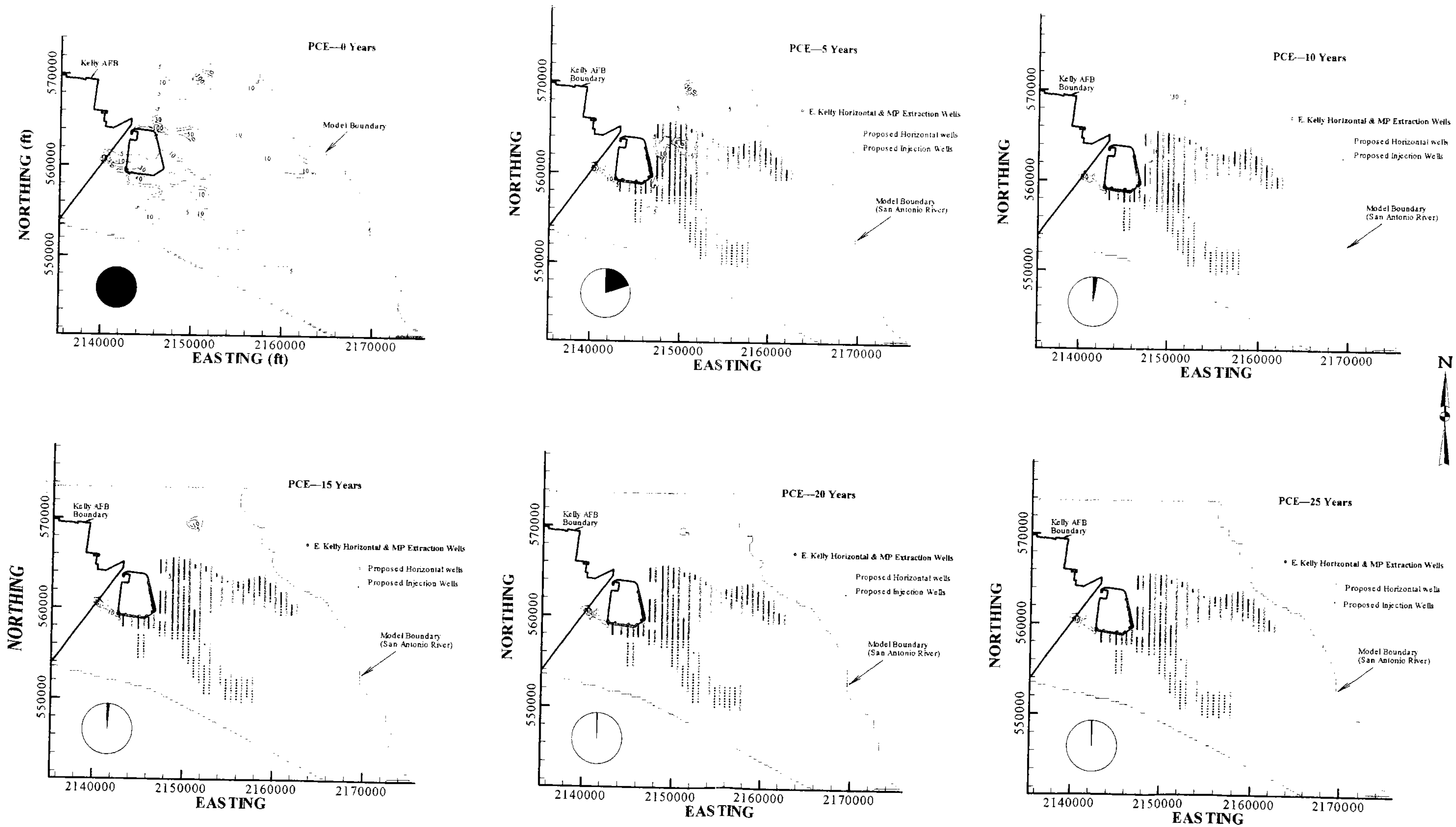


Figure 5-24 The Least Feasible Option C: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

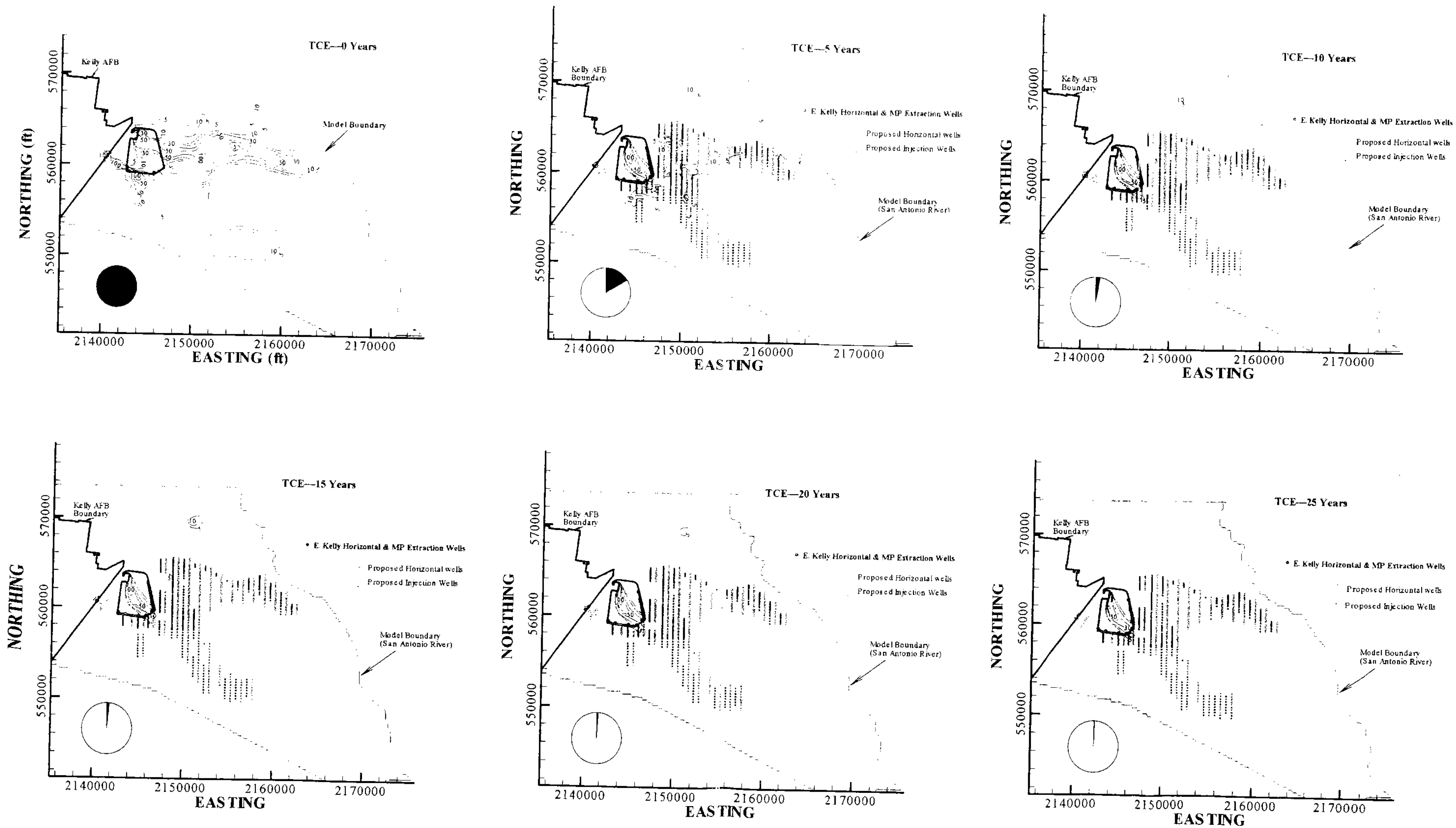


Figure 5-25 The Least Feasible Option C: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

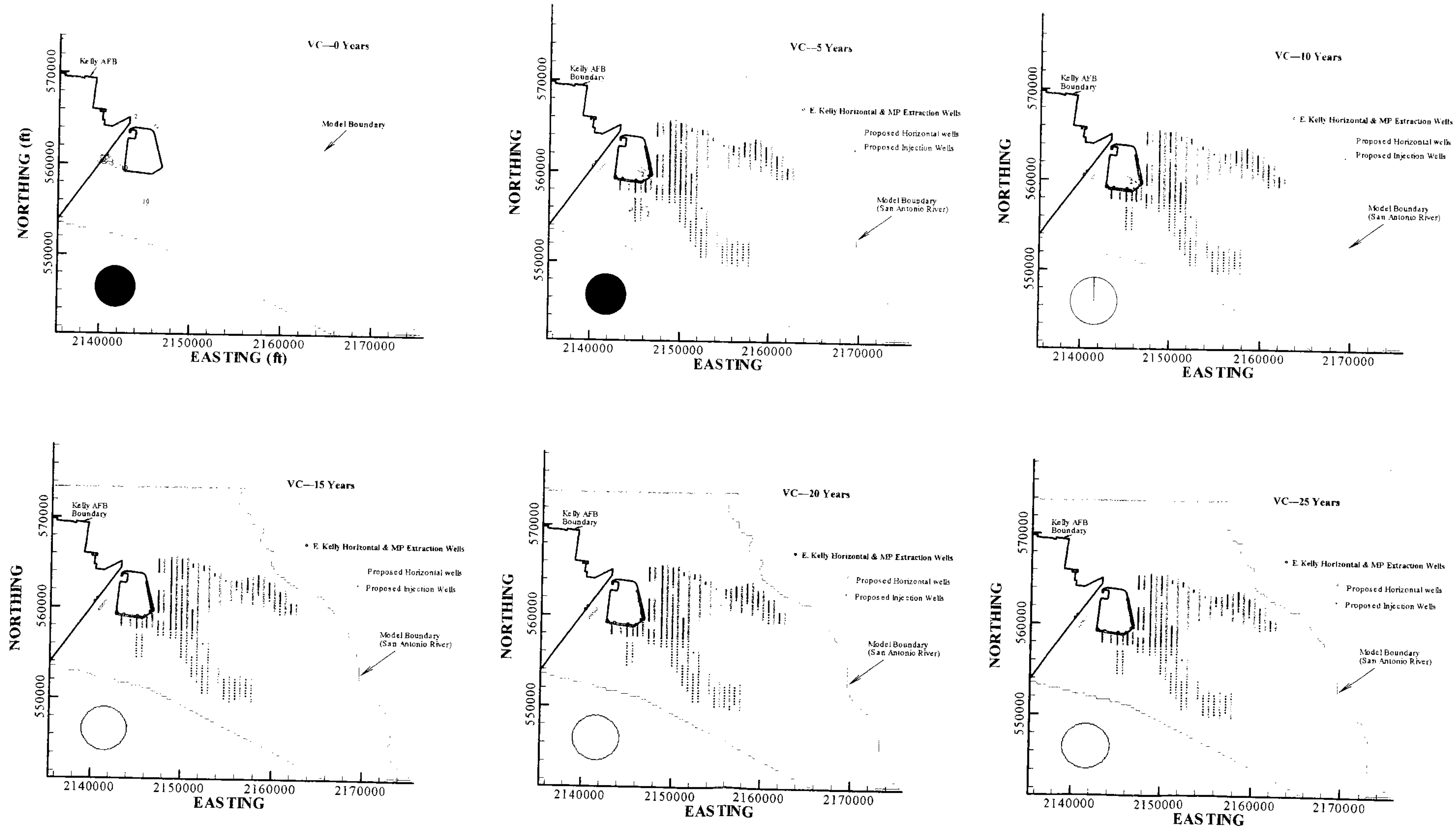


Figure 5-26 The Least Feasible Option C: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

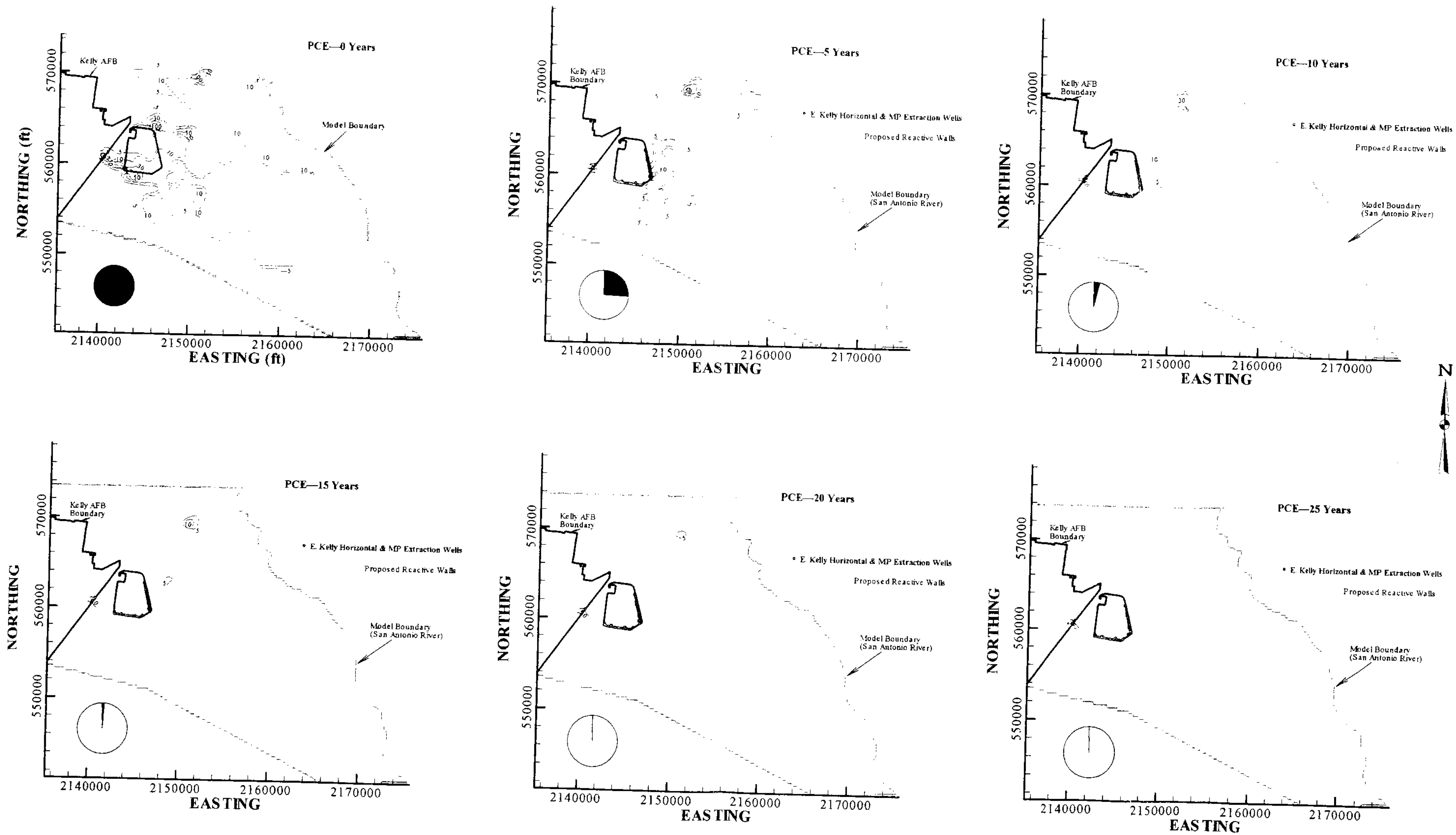


Figure 5-27 The Least Feasible Option E. Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

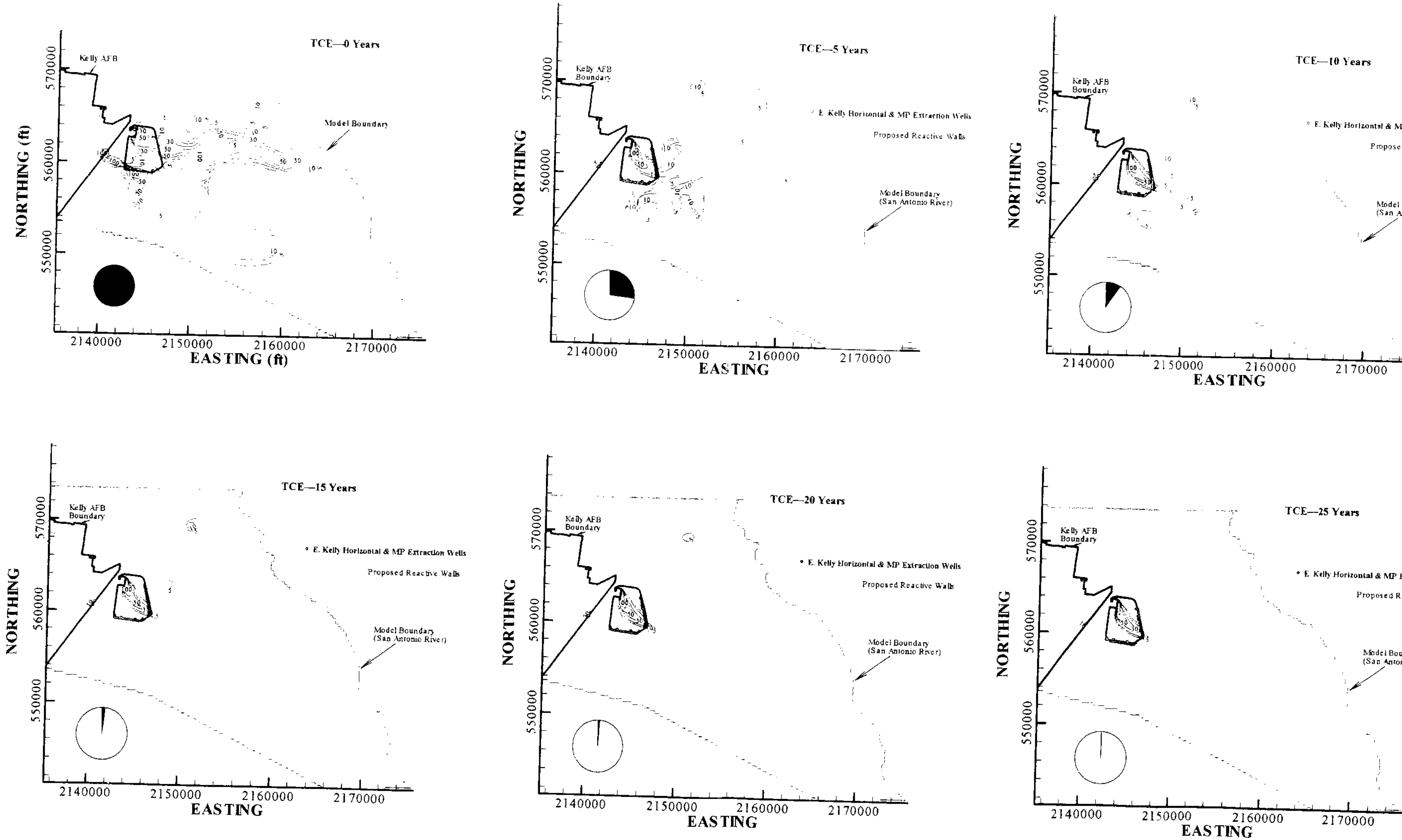


Figure 5-28 The Least Feasible Option E: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

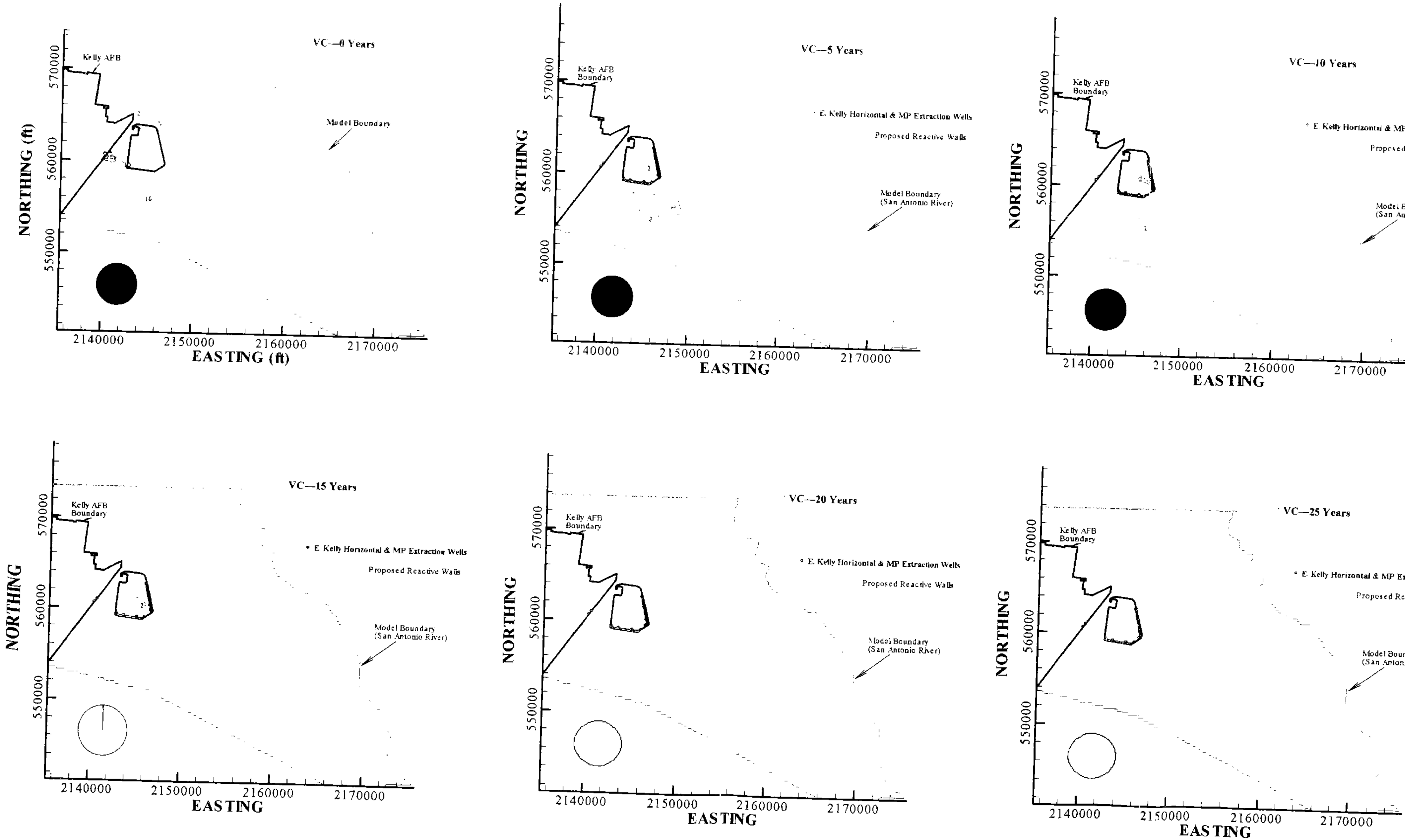


Figure 5-29 The Least Feasible Option E: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

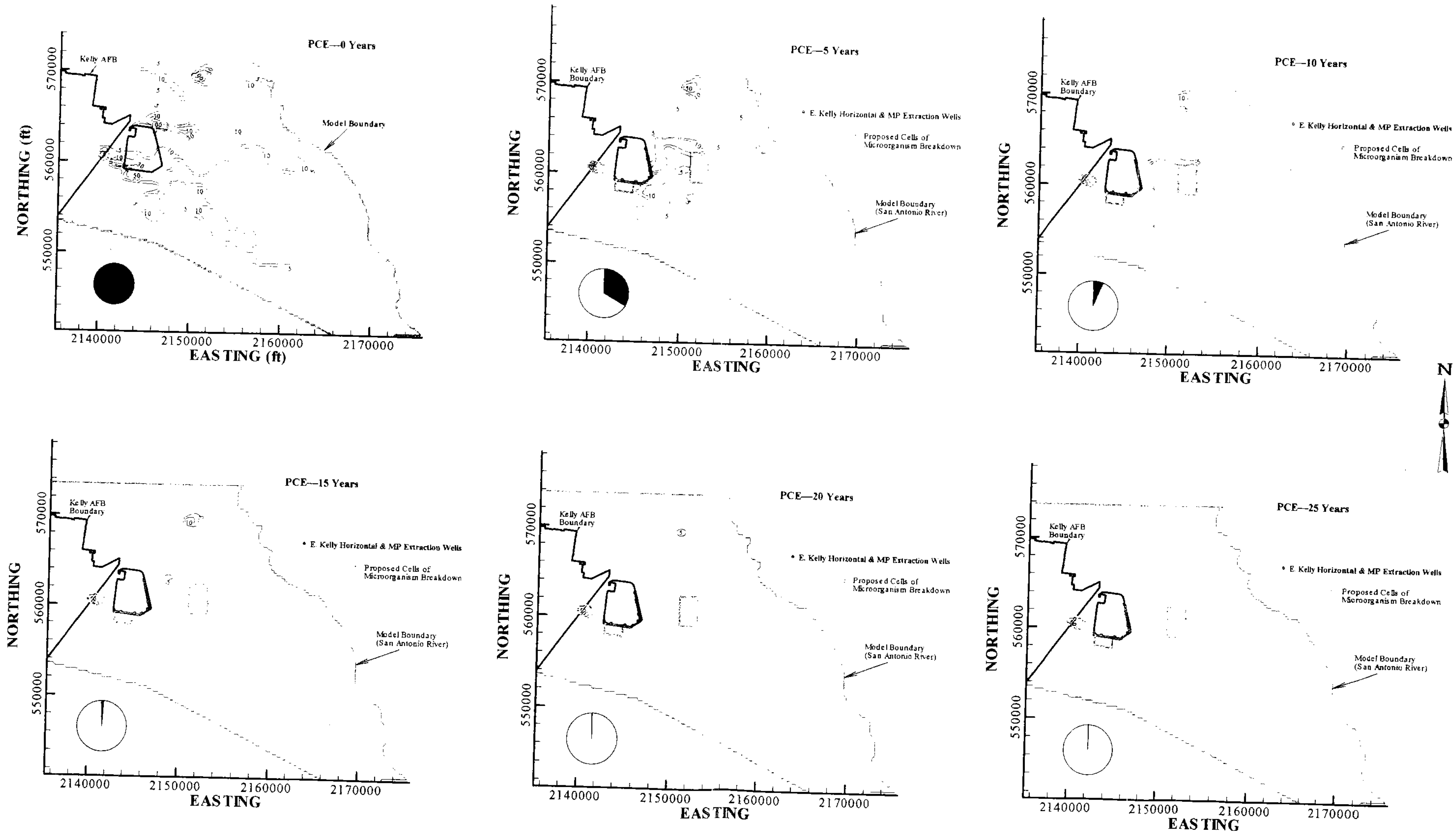


Figure 5-30 The Least Feasible Option G: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

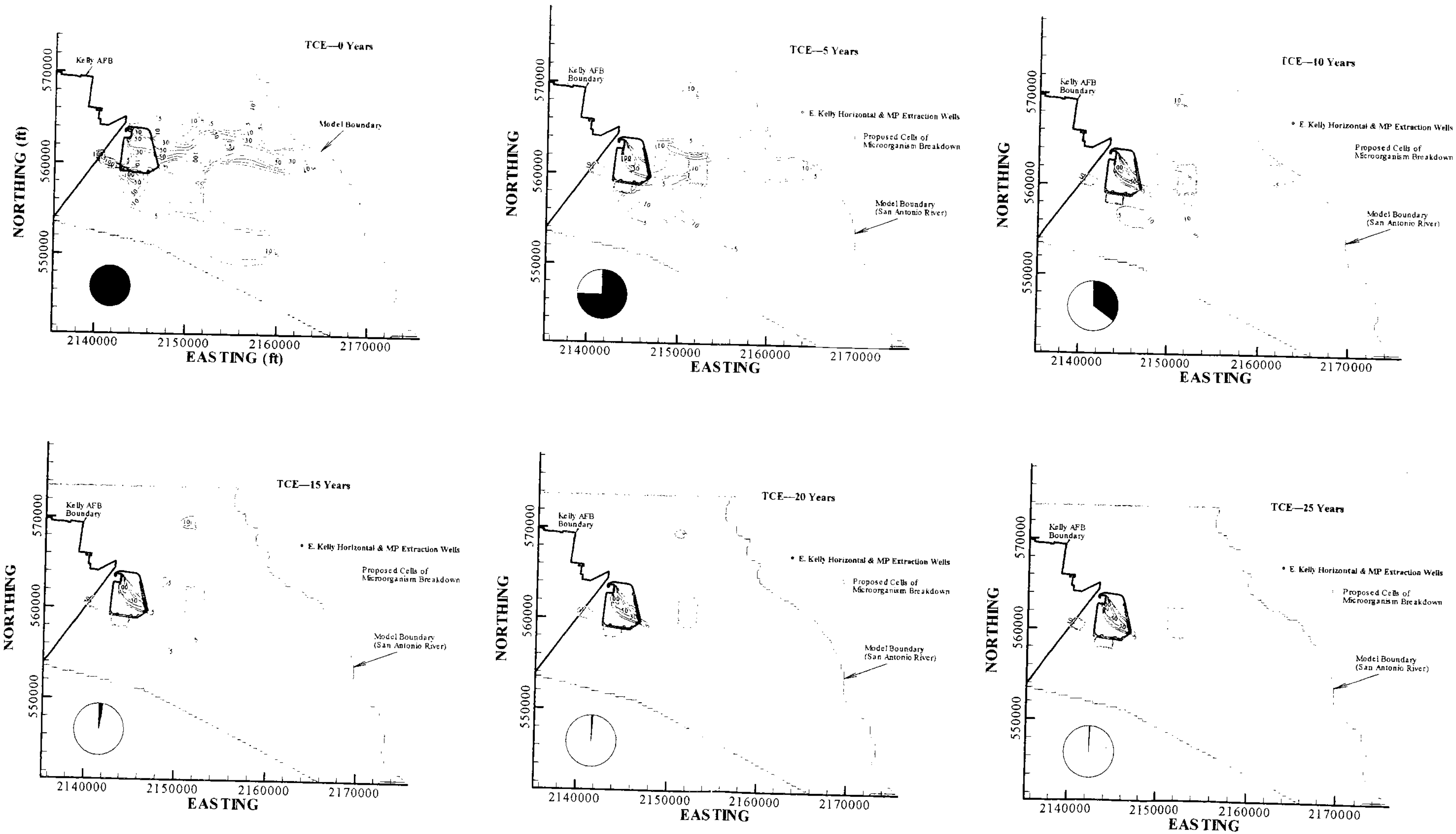


Figure 5-31 The Least Feasible Option G: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

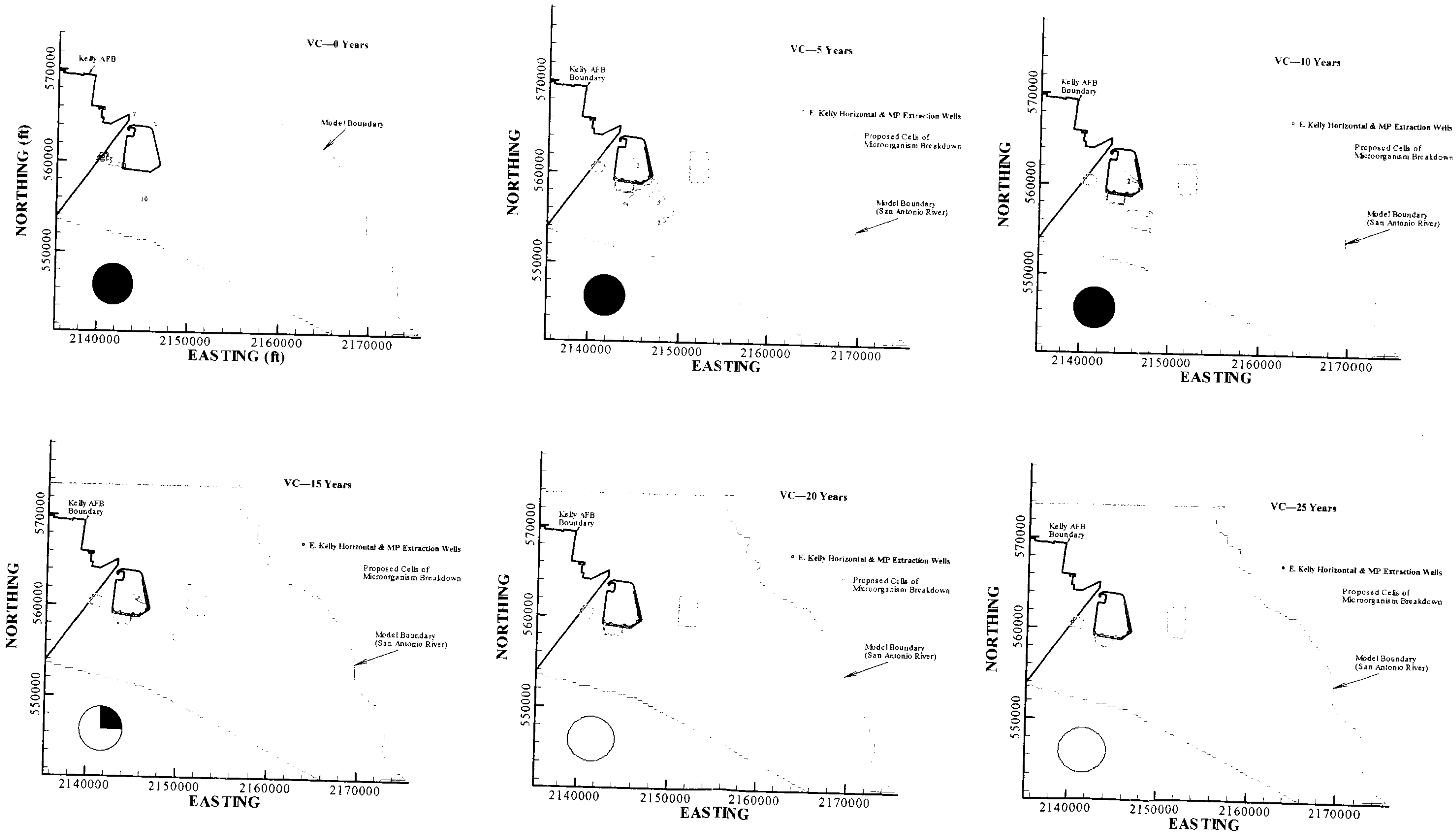


Figure 5-32 The Least Feasible Option G: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

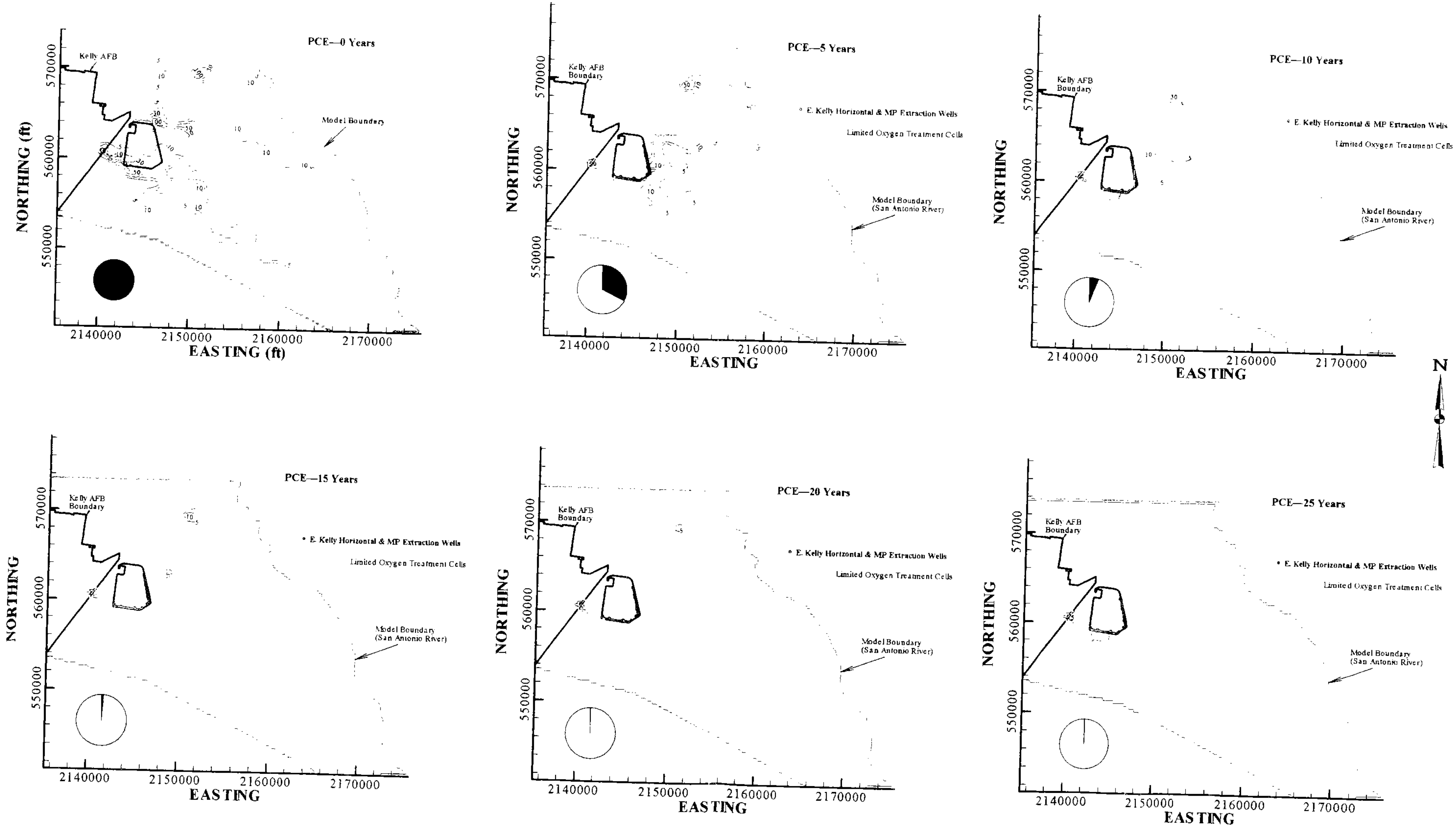


Figure 5-33 The Least Feasible Option H: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

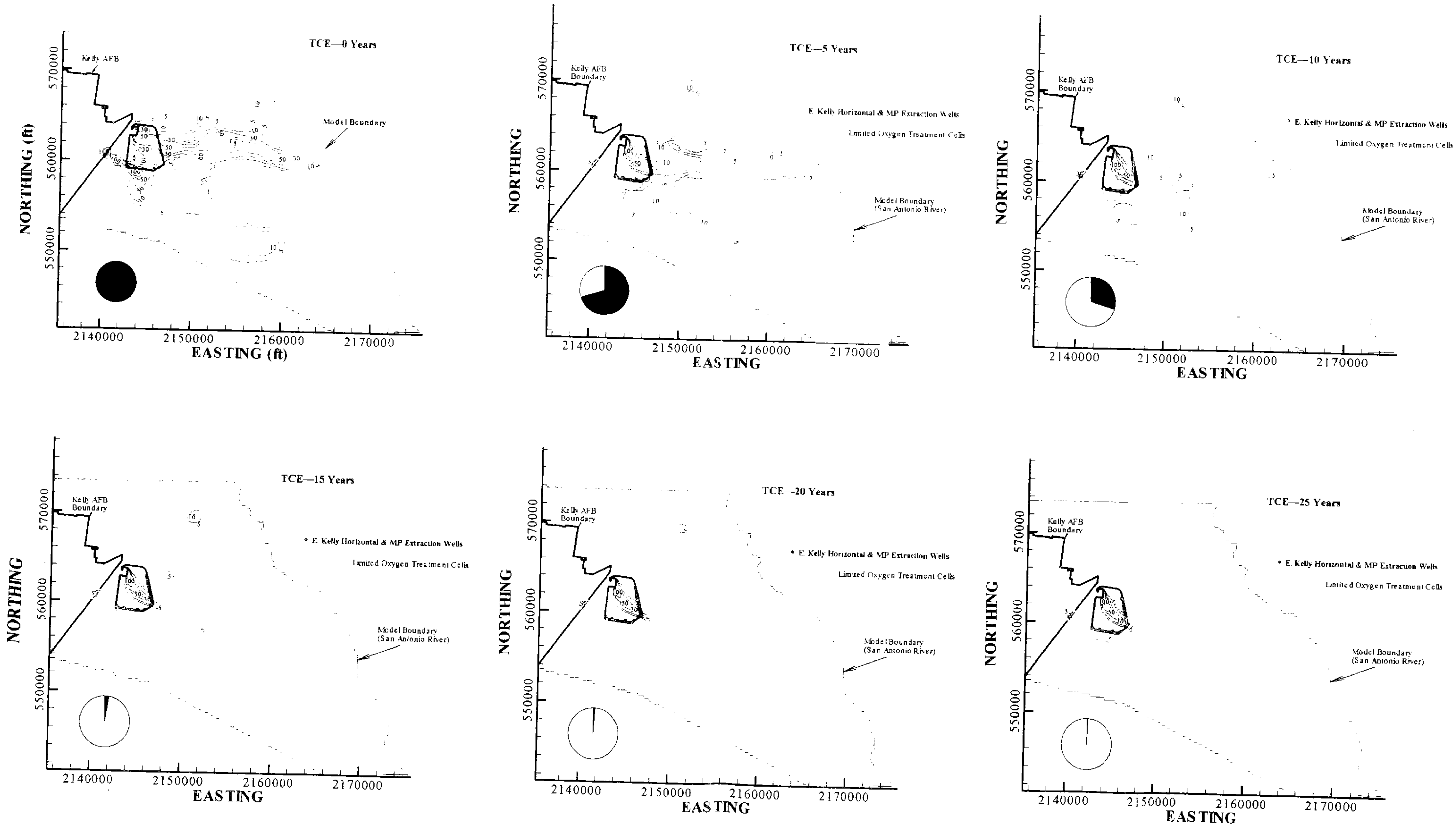


Figure 5-34 The Least Feasible Option H: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

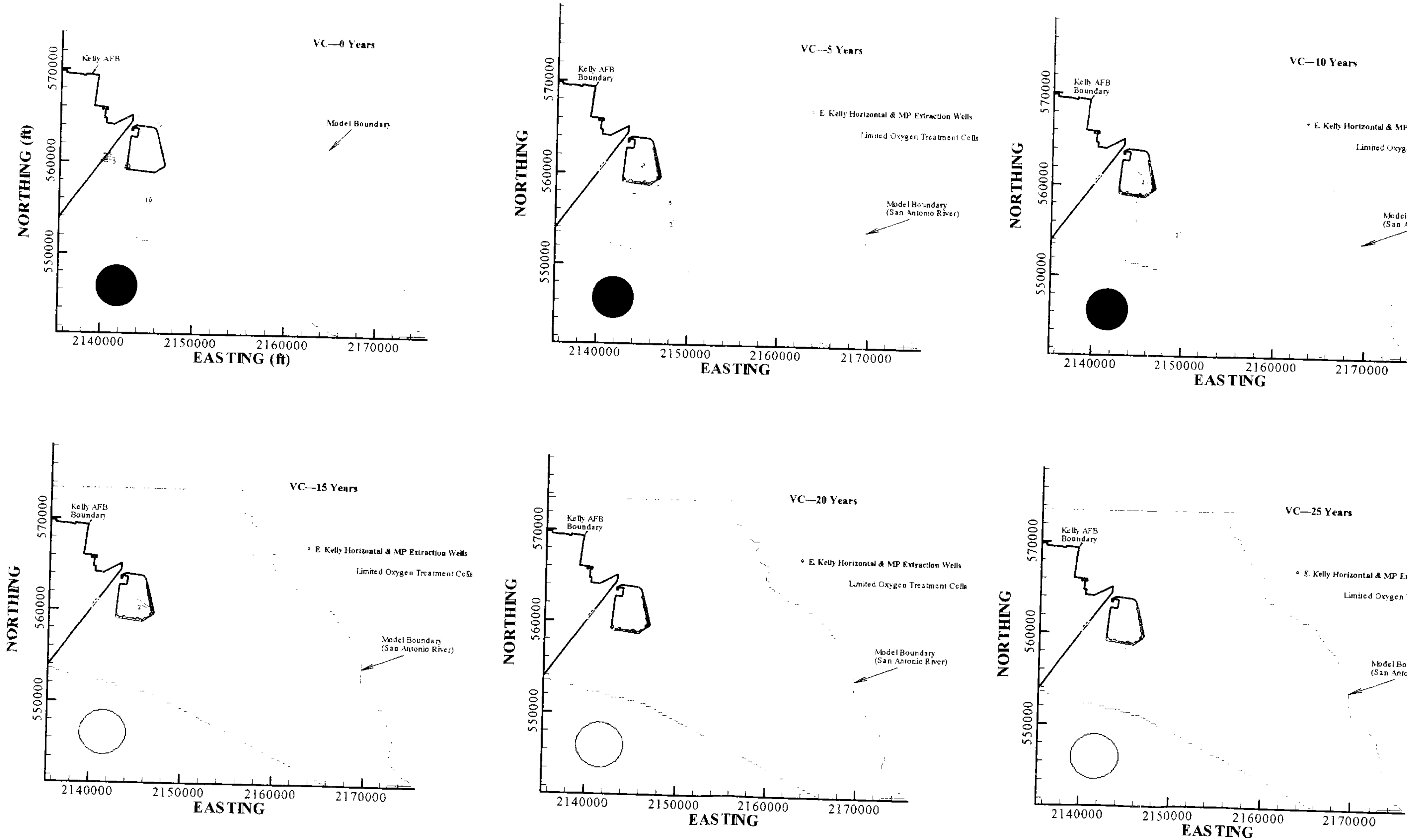


Figure 5-35 The Least Feasible Option H. Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

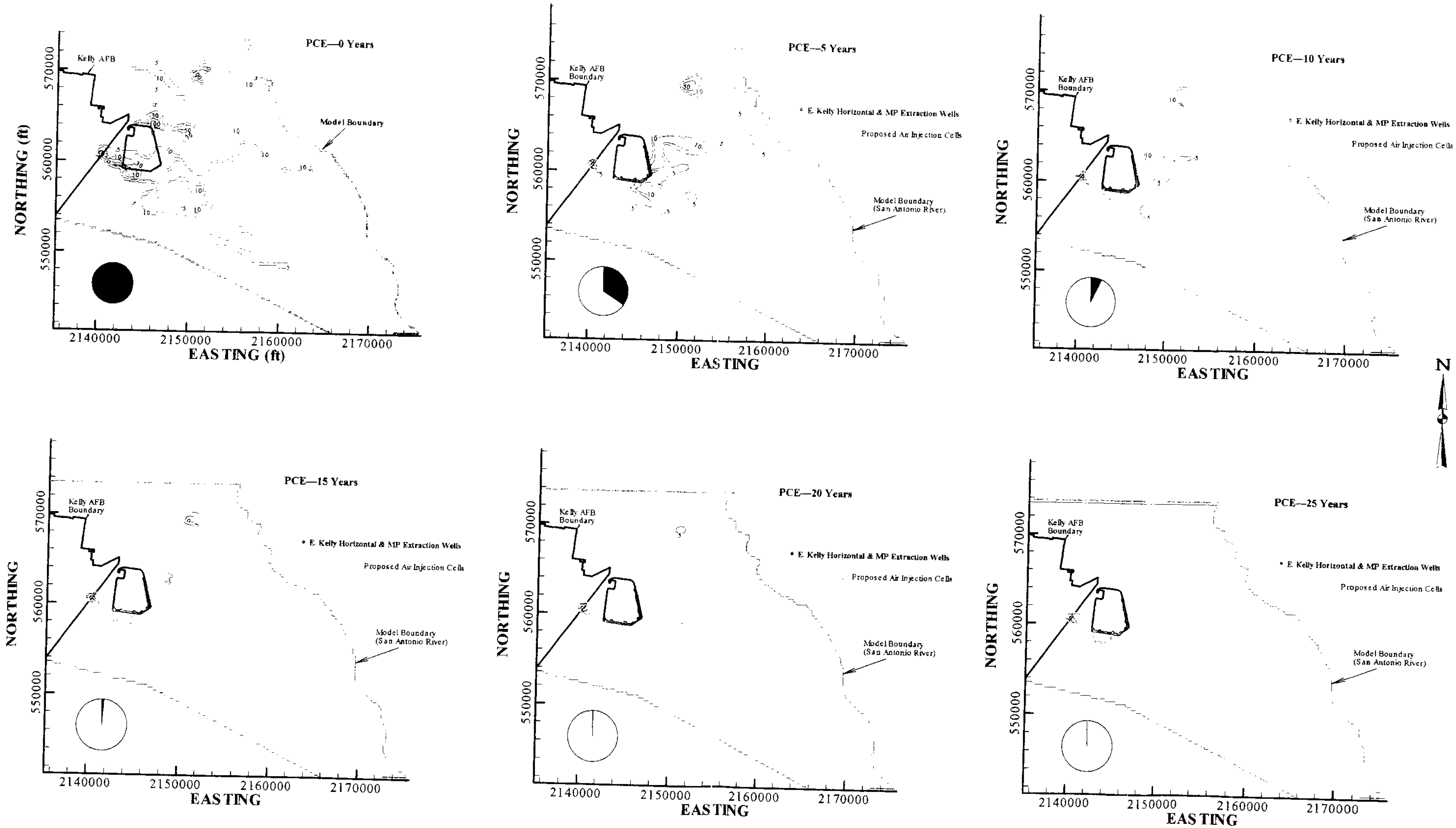


Figure 5-36 The Least Feasible Option I: Simulated PCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

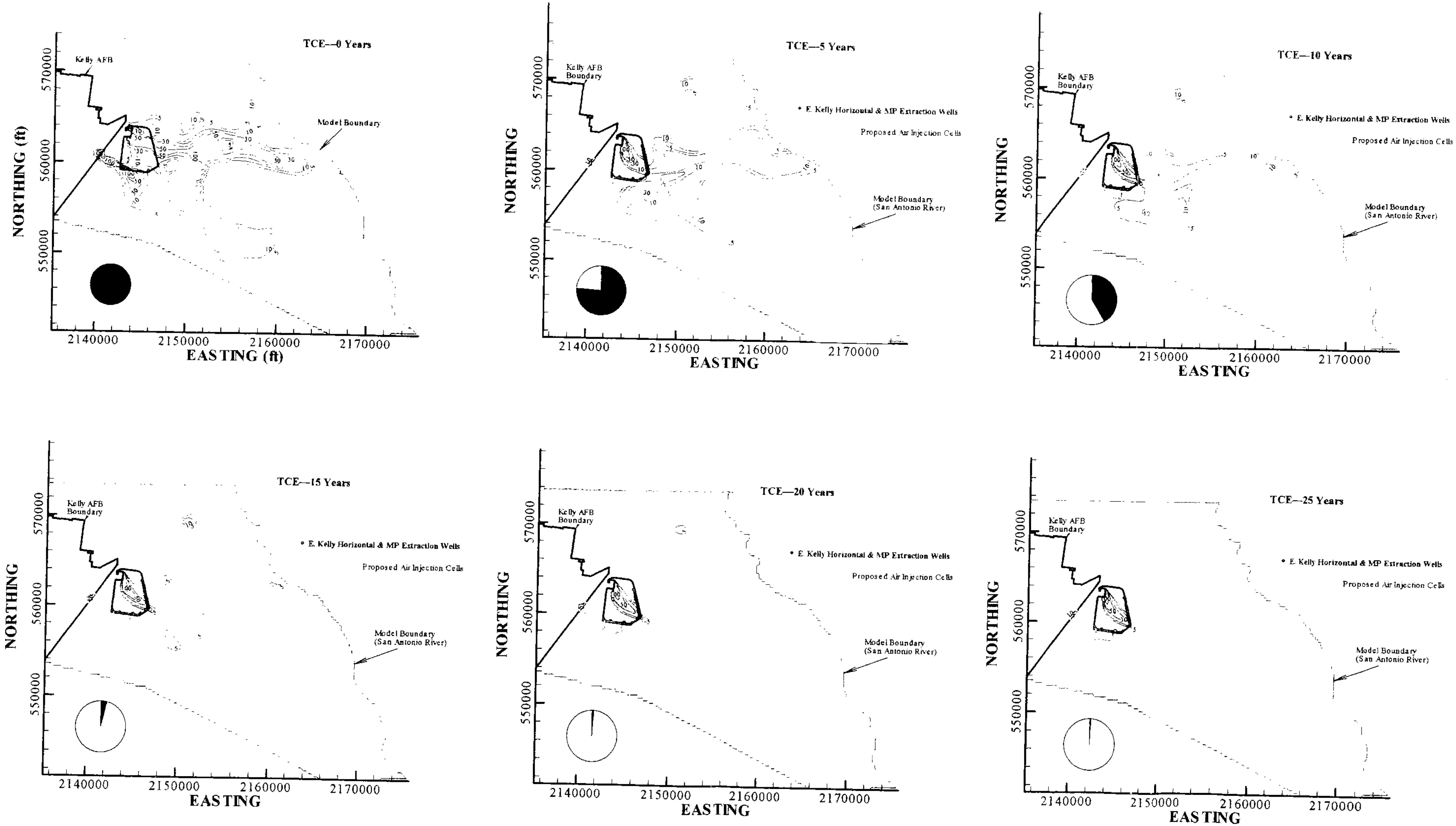


Figure 5-37 The Least Feasible Option I: Simulated TCE Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

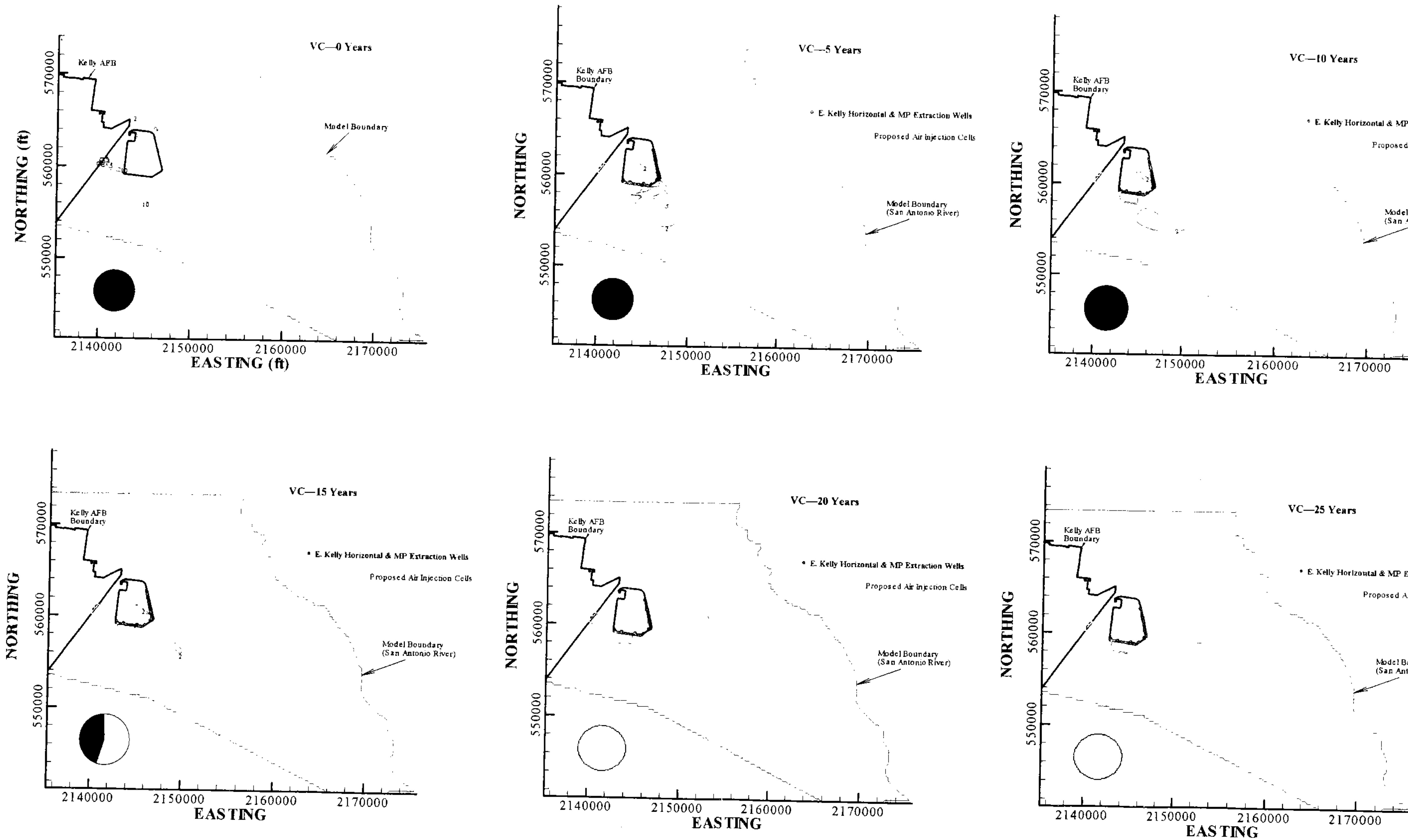


Figure 5-38 The Least Feasible Option I: Simulated VC Contours (ppb) at 5-Year Intervals (Phase 1)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

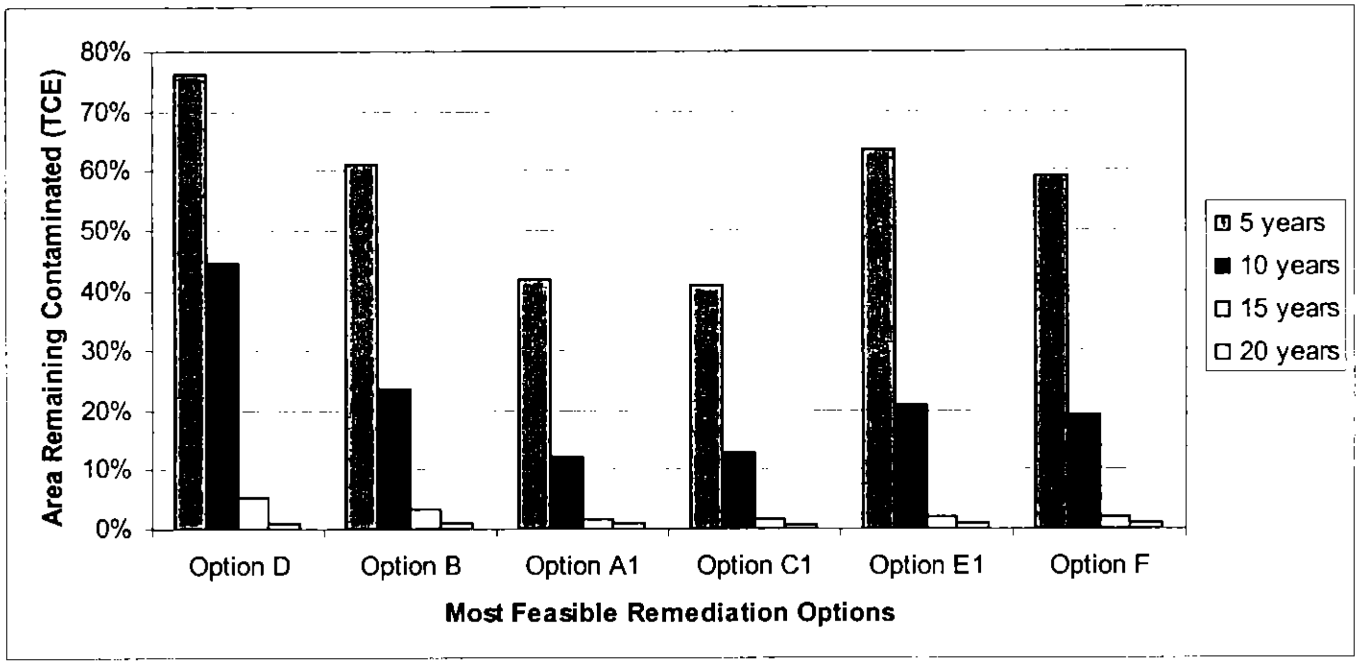


Figure 5-39 Comparison of Area Remaining TCE Contaminated among Most Feasible Remediation Options (Phase 1)

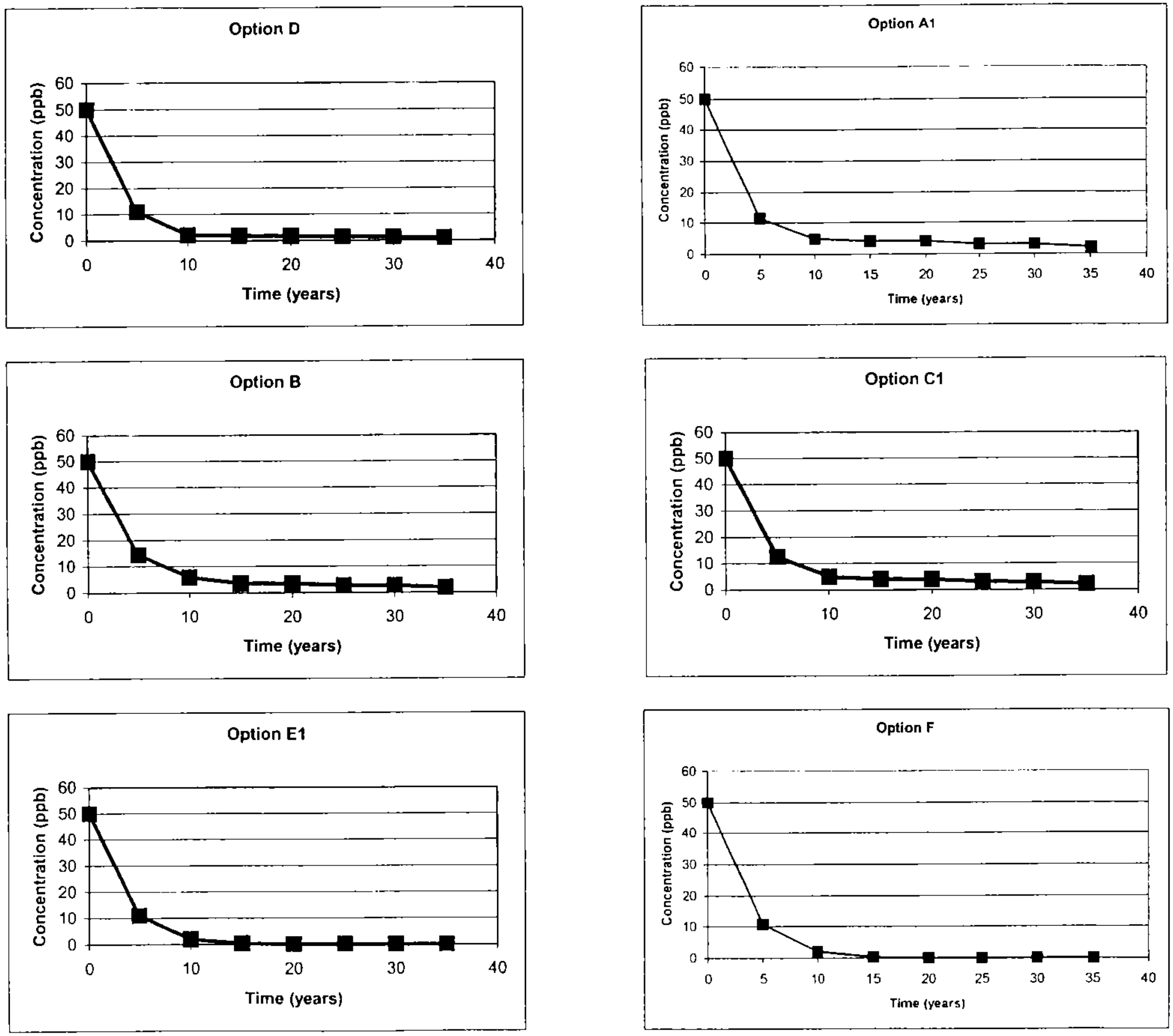


Figure 5-40 The Most Feasible Options—Maximum Concentration (ppb) Over Time for PCE at East Kelly (phase 1)

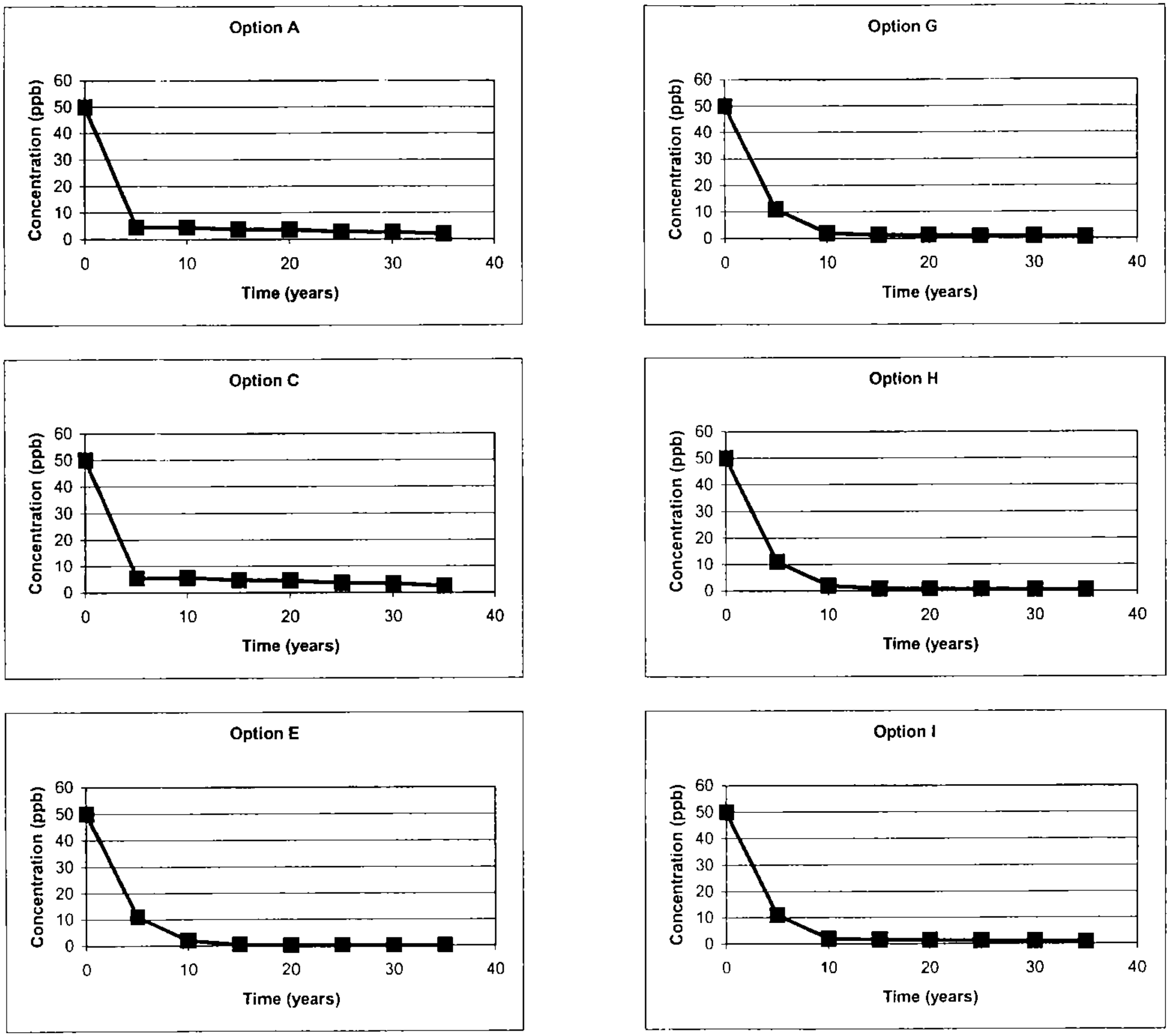


Figure 5-41 The Least Feasible Options—Maximum Concentration (ppb) Over Time for PCE at East Kelly (Phase 1)

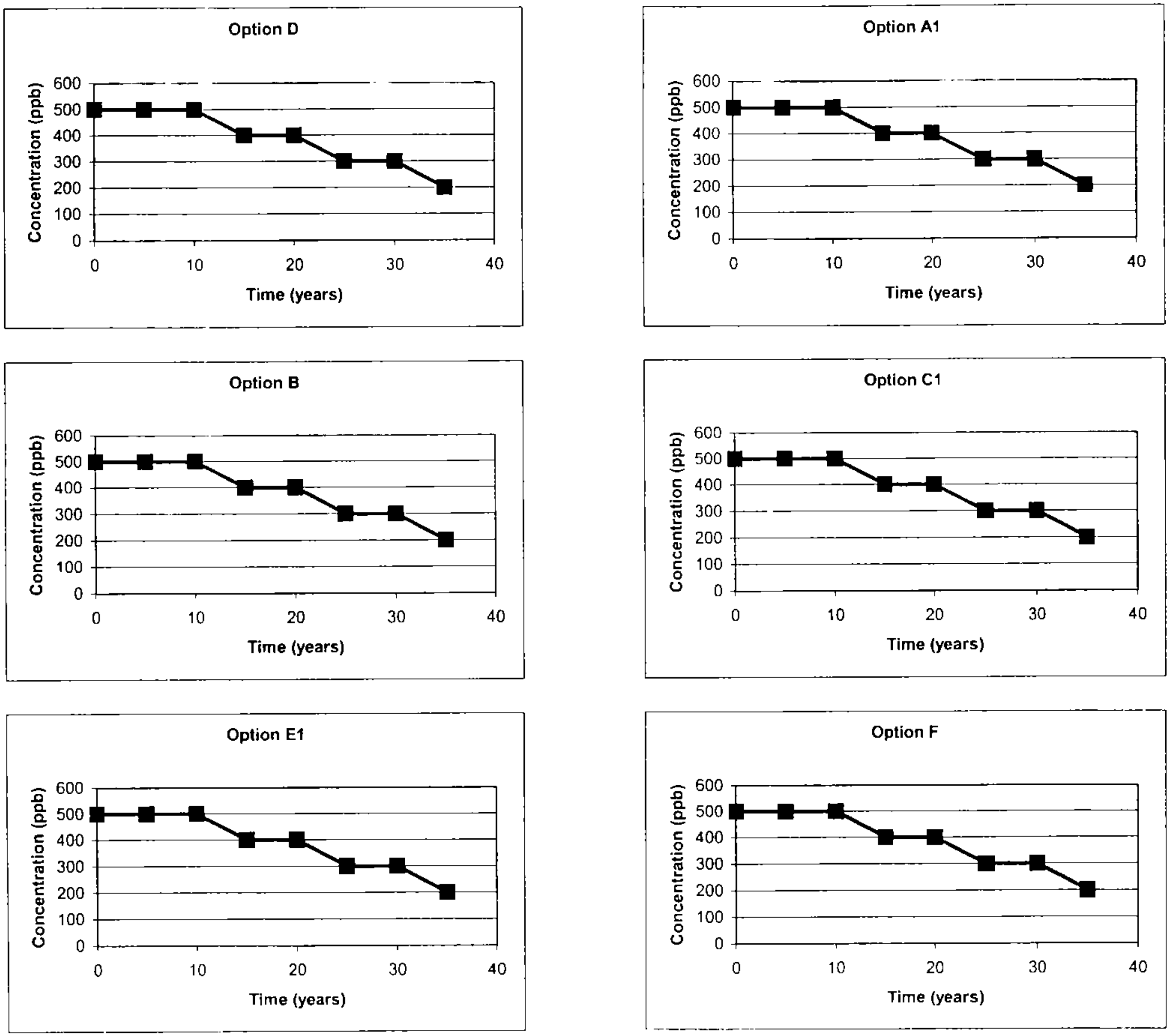


Figure 5-42 The Most Feasible Options—Maximum Concentration (ppb) Over Time for TCE at East Kelly (Phase 1)

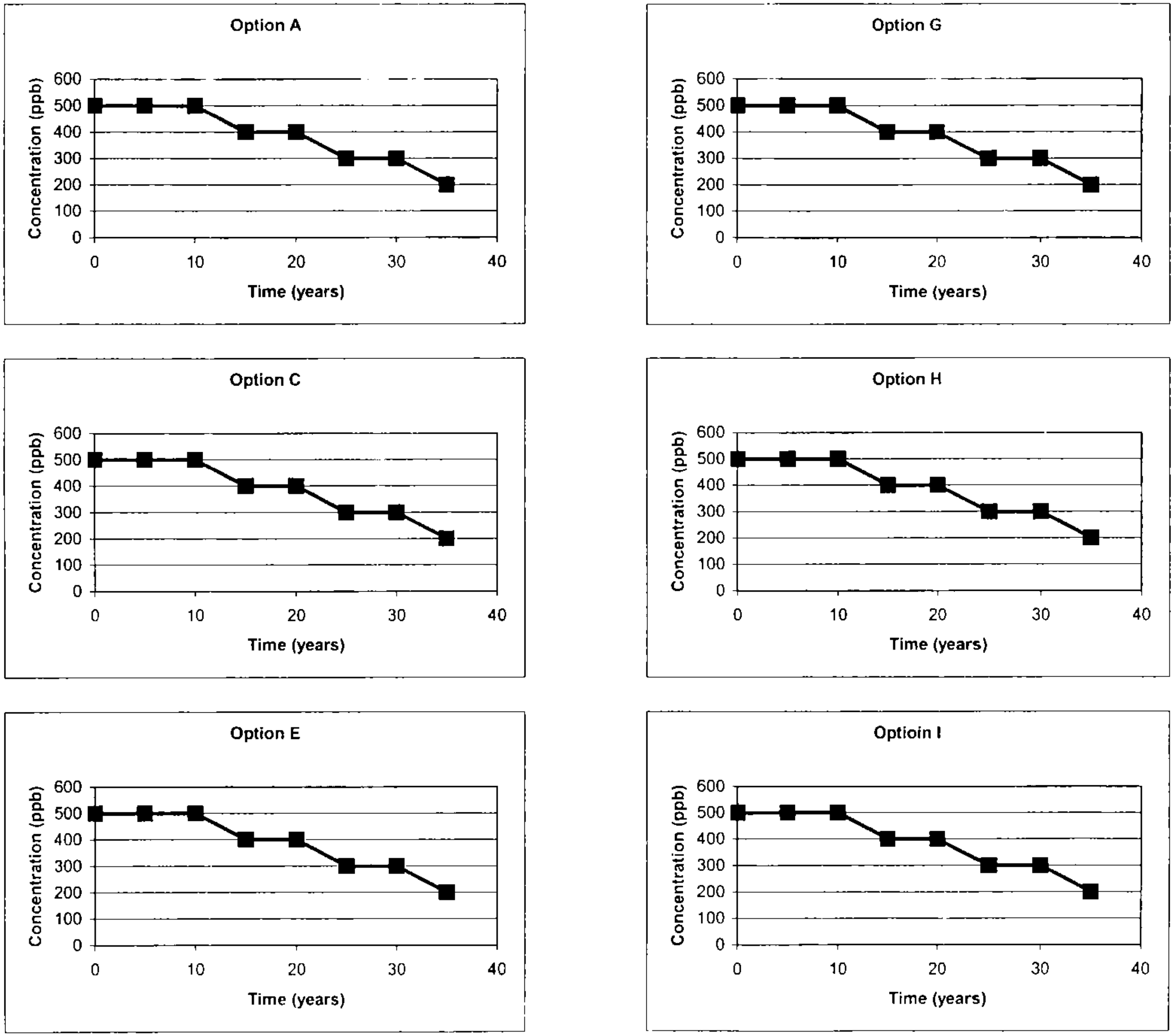


Figure 5-43 The Least Feasible Options—Maximum Concentration (ppb) Over Time for TCE at East Kelly (Phase 1)

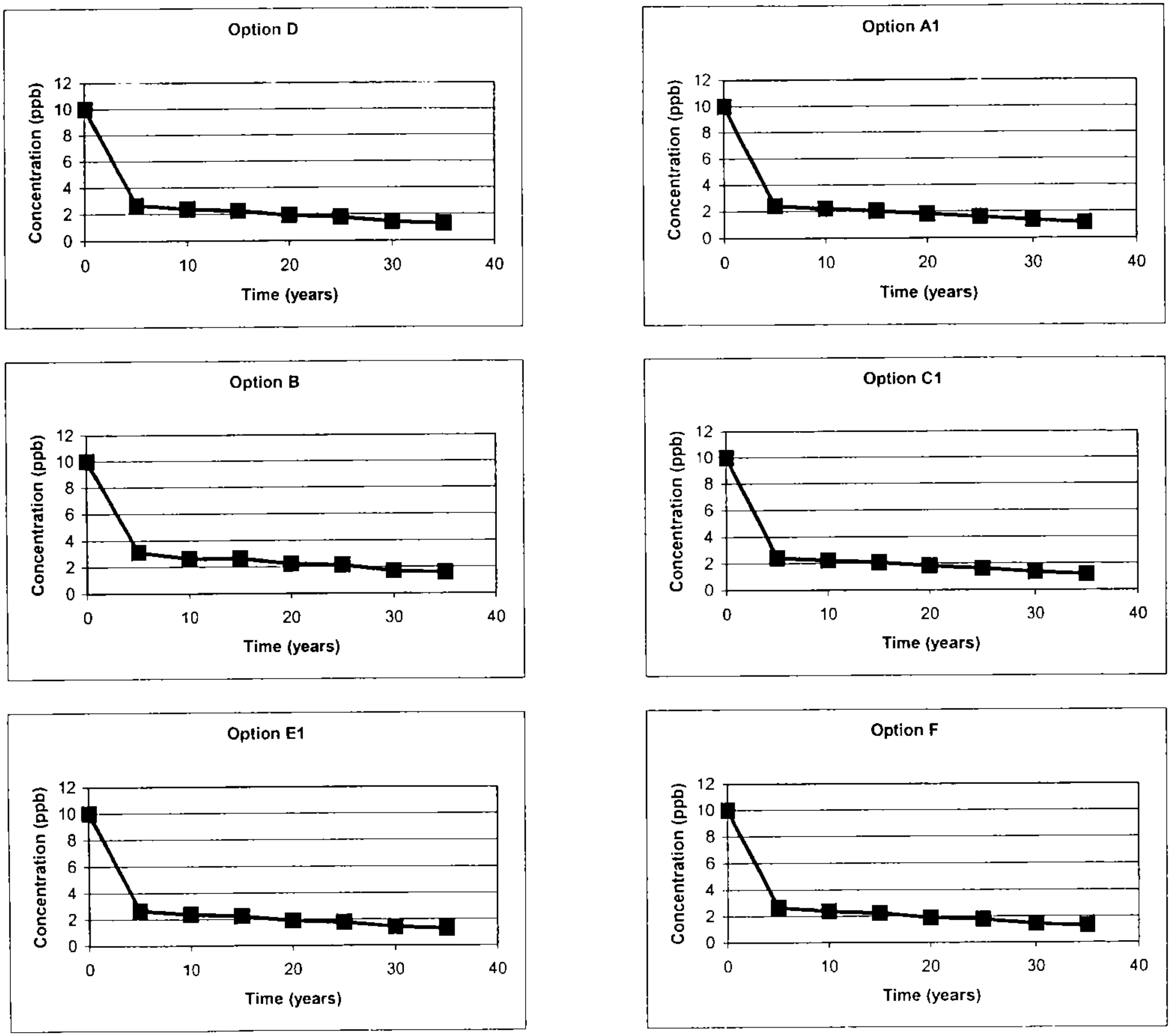


Figure 5-44 The Most Feasible Options—Maximum Concentration (ppb) Over Time for VC at East Kelly (Phase 1)

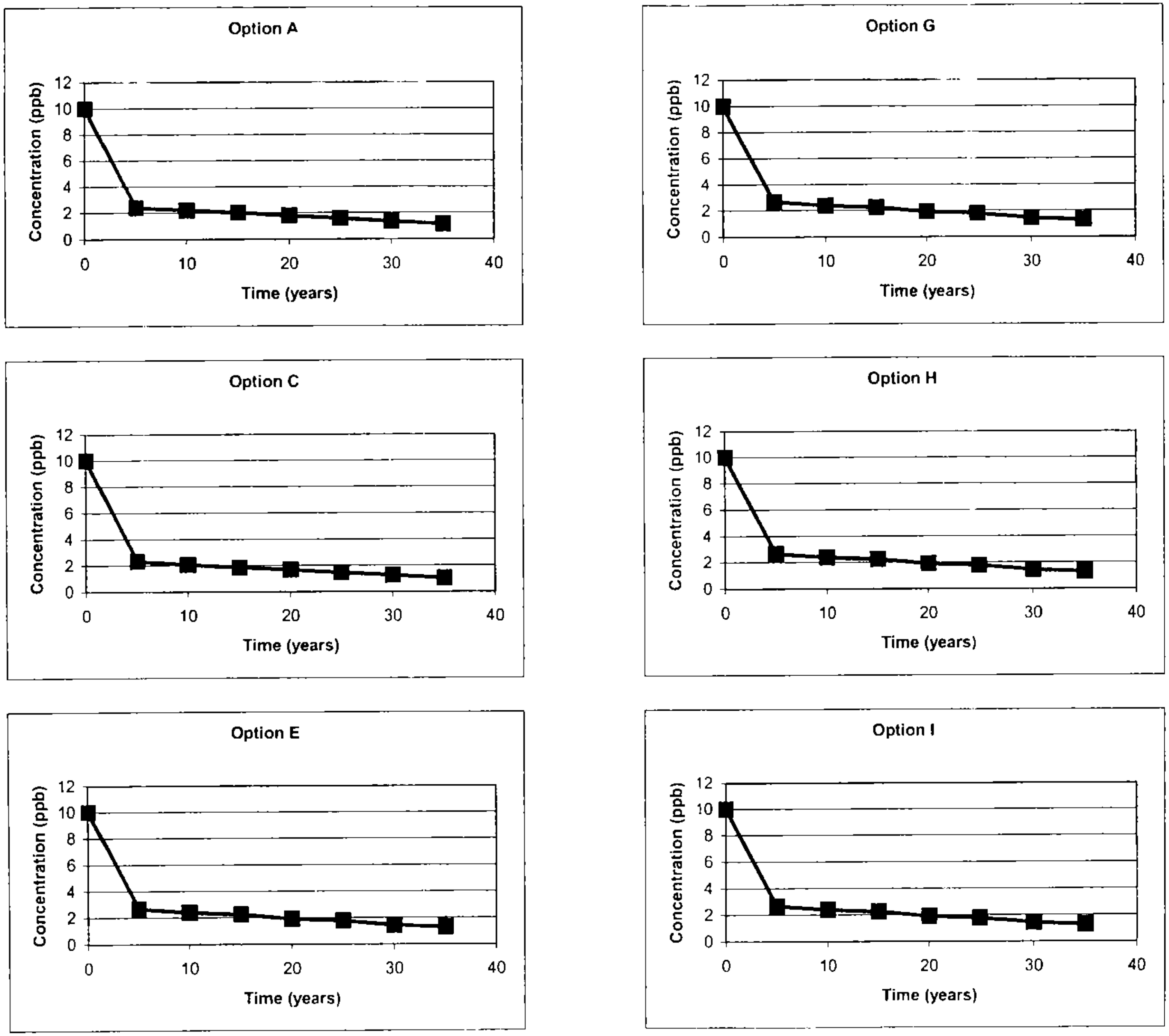


Figure 5-45 The Least Feasible Options—Maximum Concentration (ppb) Over Time for VC at East Kelly (Phase 1)

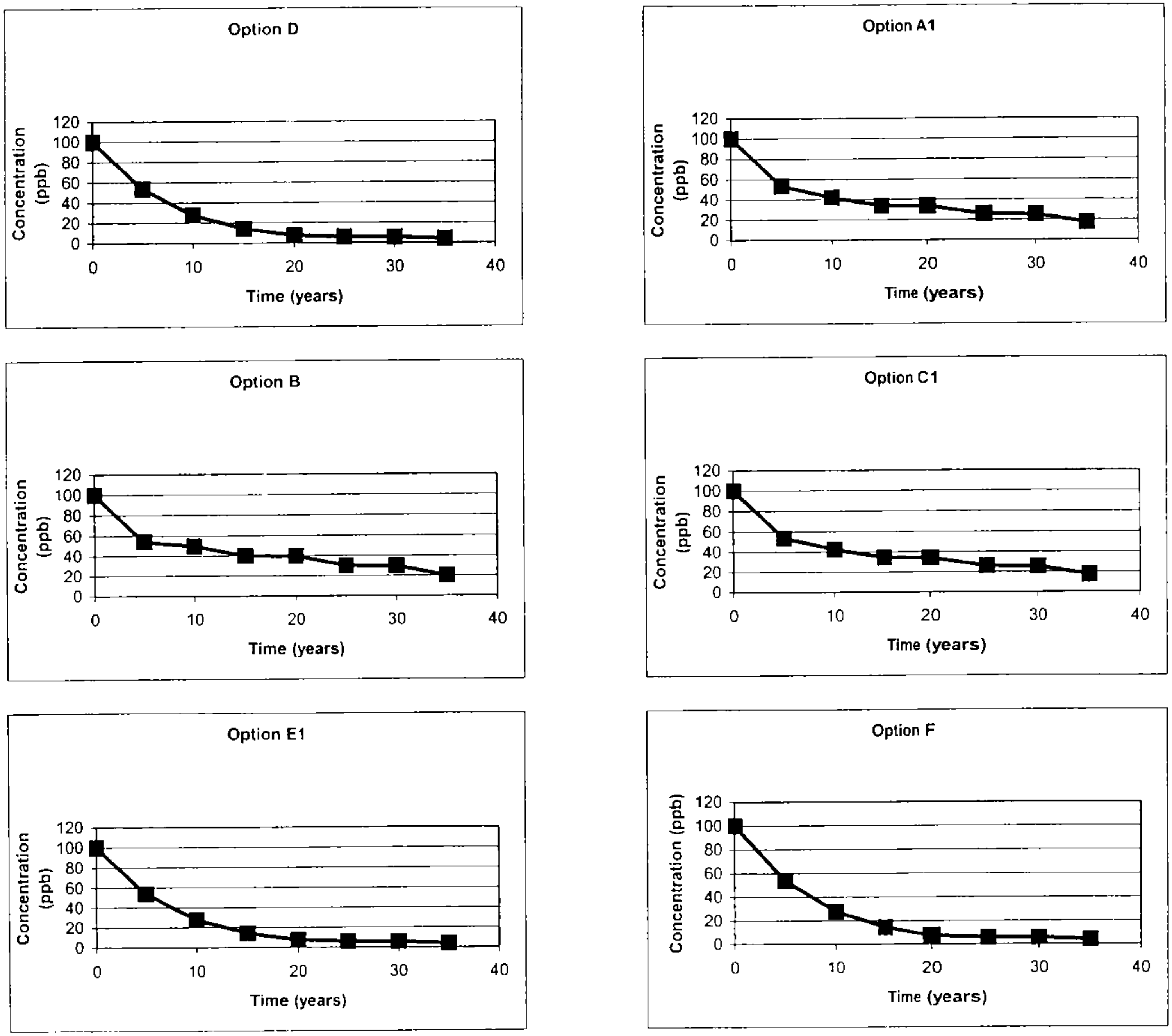


Figure 5-46 The Most Feasible Options—Maximum Concentration (ppb) Over Time for PCE Off Base (Phase 1)

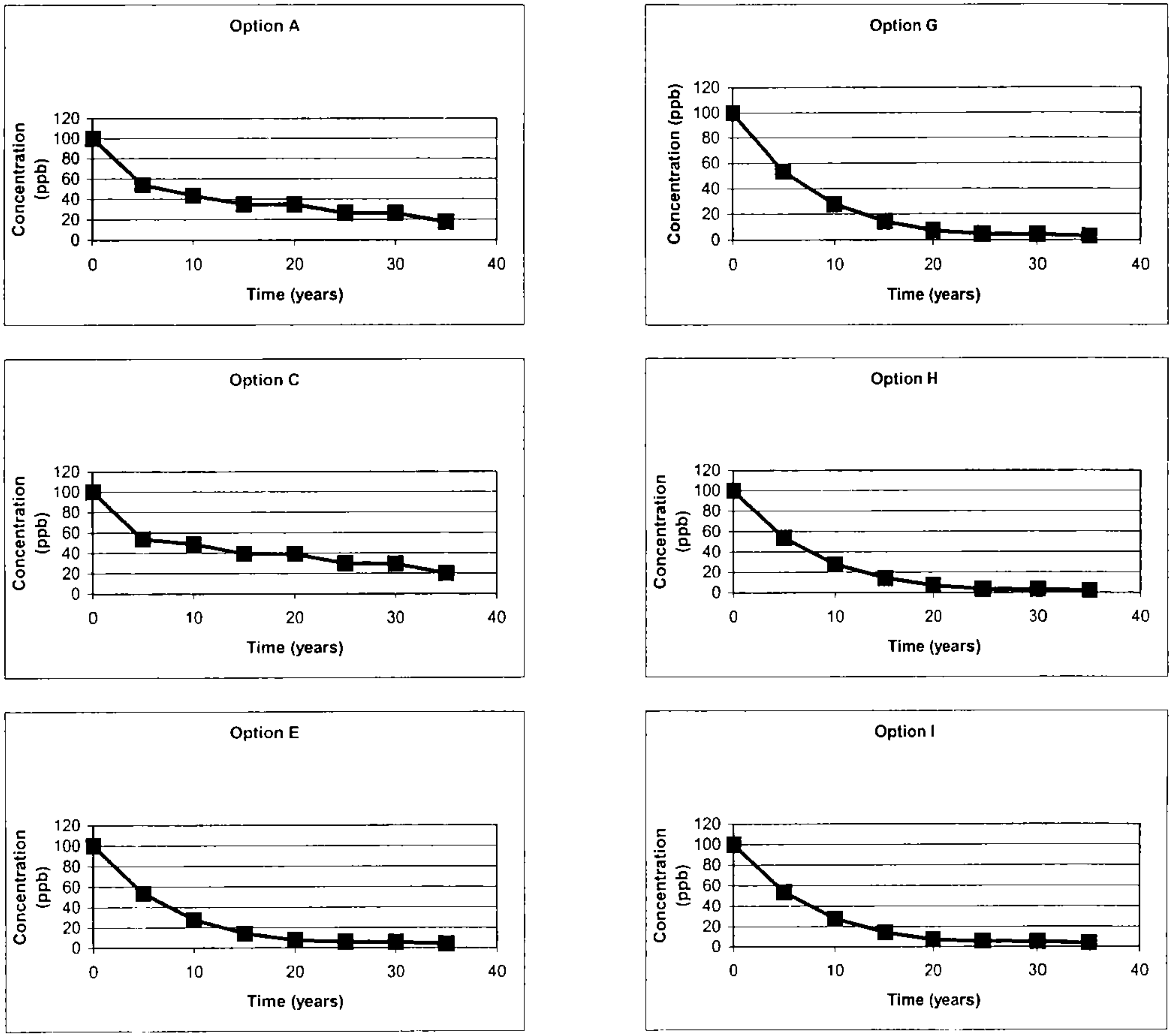


Figure 5-47 The Least Feasible Options—Maximum Concentration (ppb) Over Time for PCE Off Base (Phase I)

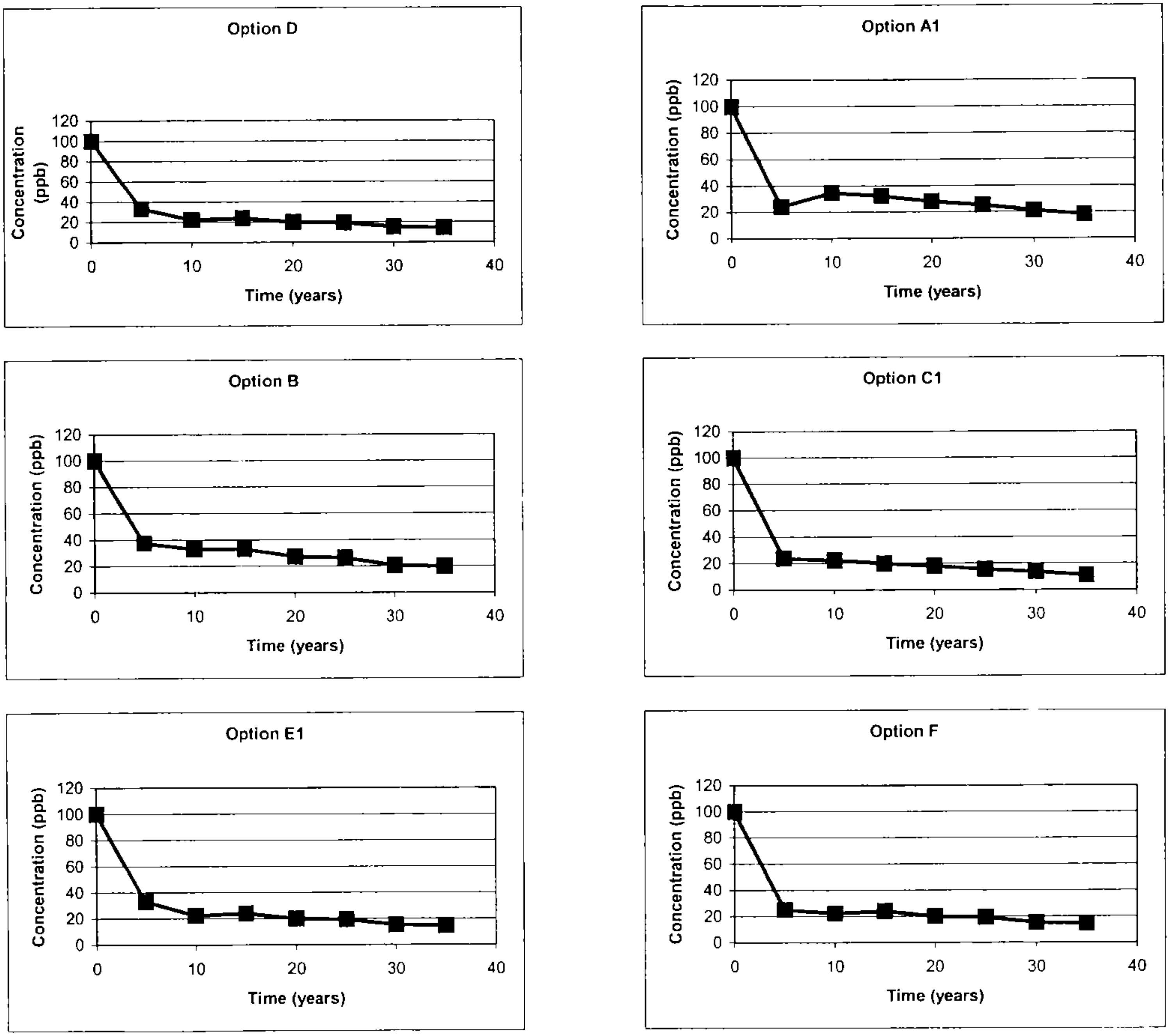


Figure 5-48 The Most Feasible Options—Maximum Concentration (ppb) Over Time for TCE Off Base (Phase 1)

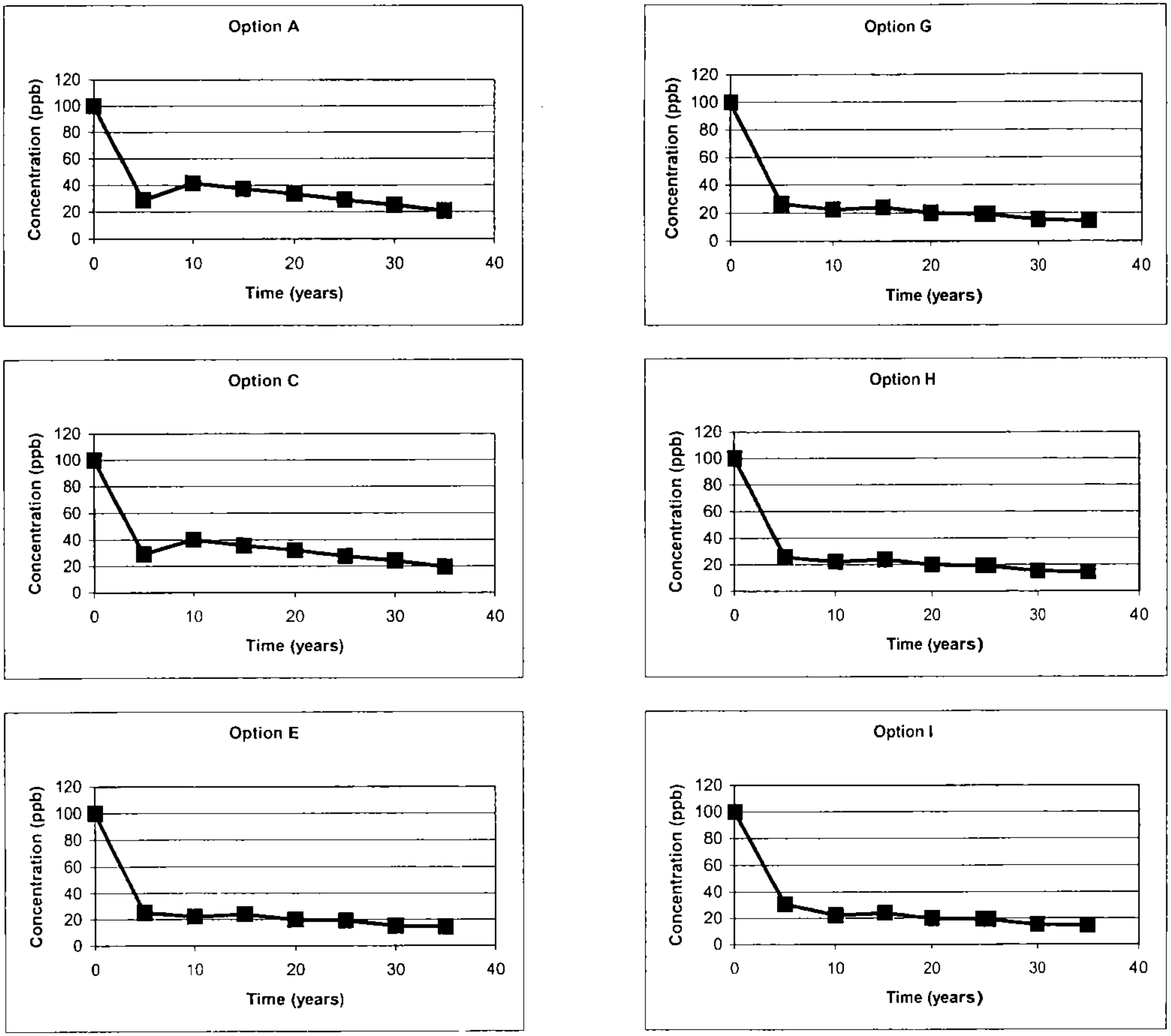


Figure 5-49 The Least Feasible Options—Maximum Concentration (ppb) Over Time for TCE Off Base (Phase 1)

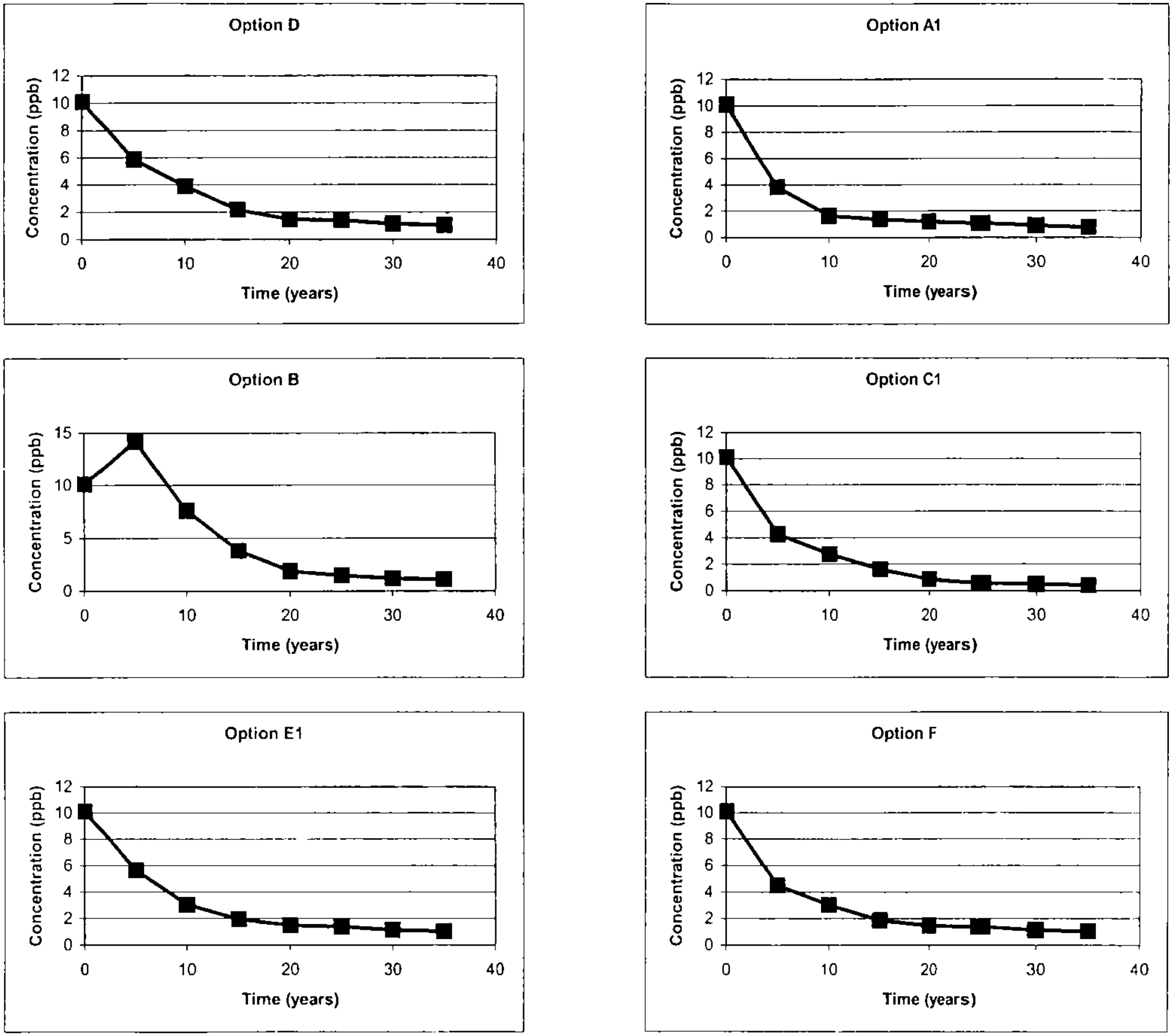


Figure 5-50 The Most Feasible Options —Maximum Concentration (ppb) Over Time for VC Off Base (Phase 1)

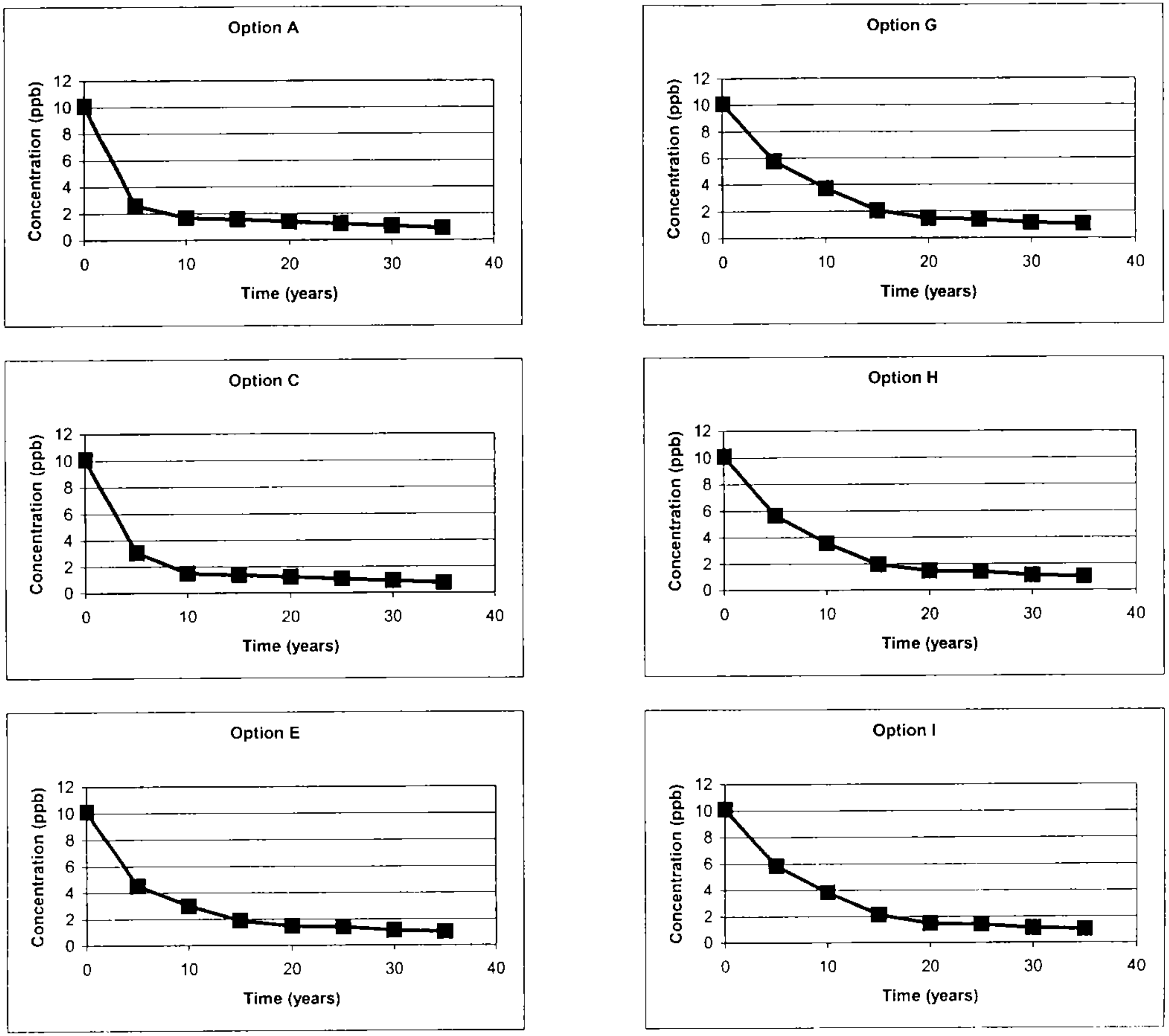


Figure 5-51 The Least Feasible Options —Maximum Concentration (ppb) Over Time for VC Off Base (Phase 1)

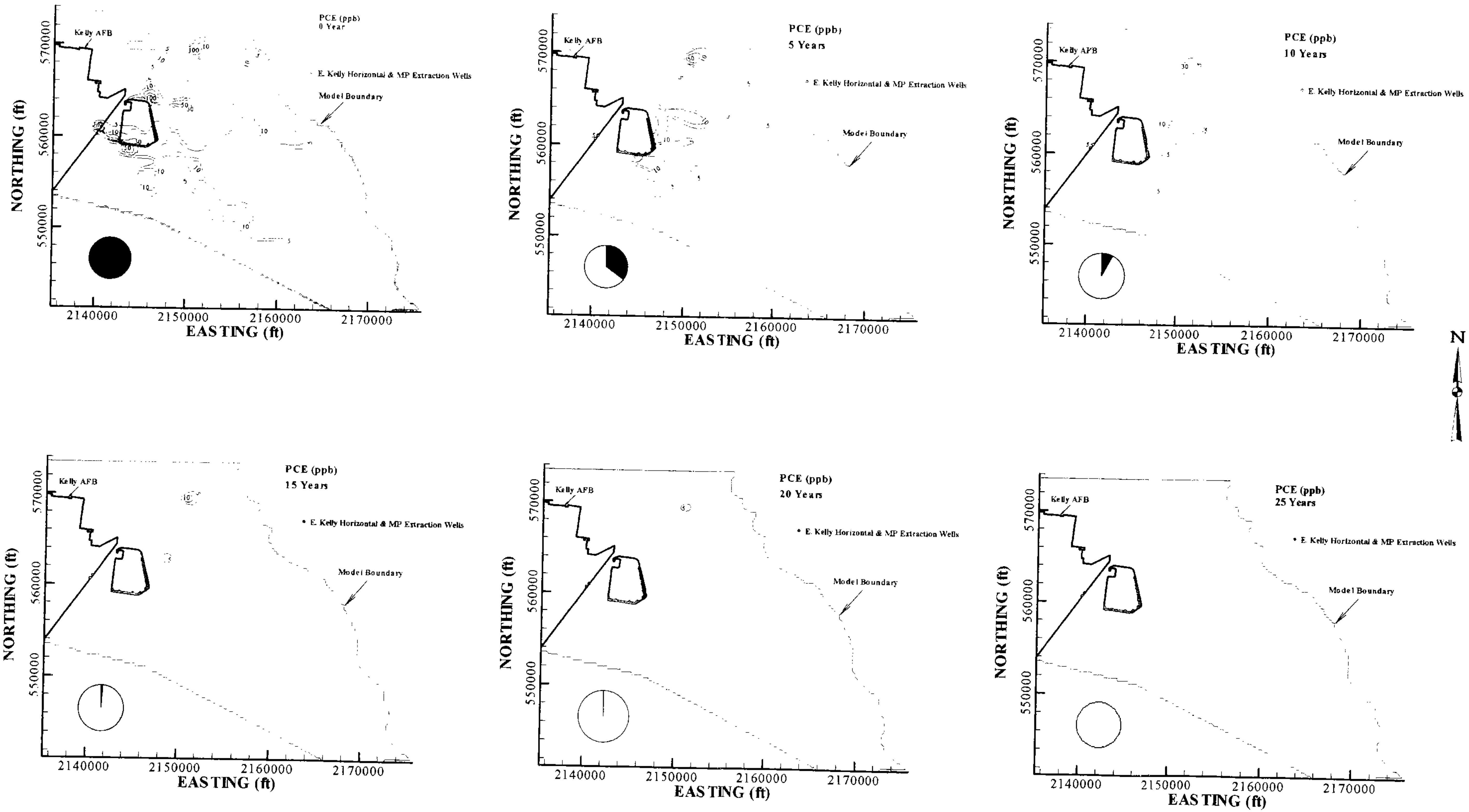


Figure 5-52 The Most Feasible Option D: Simulated PCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

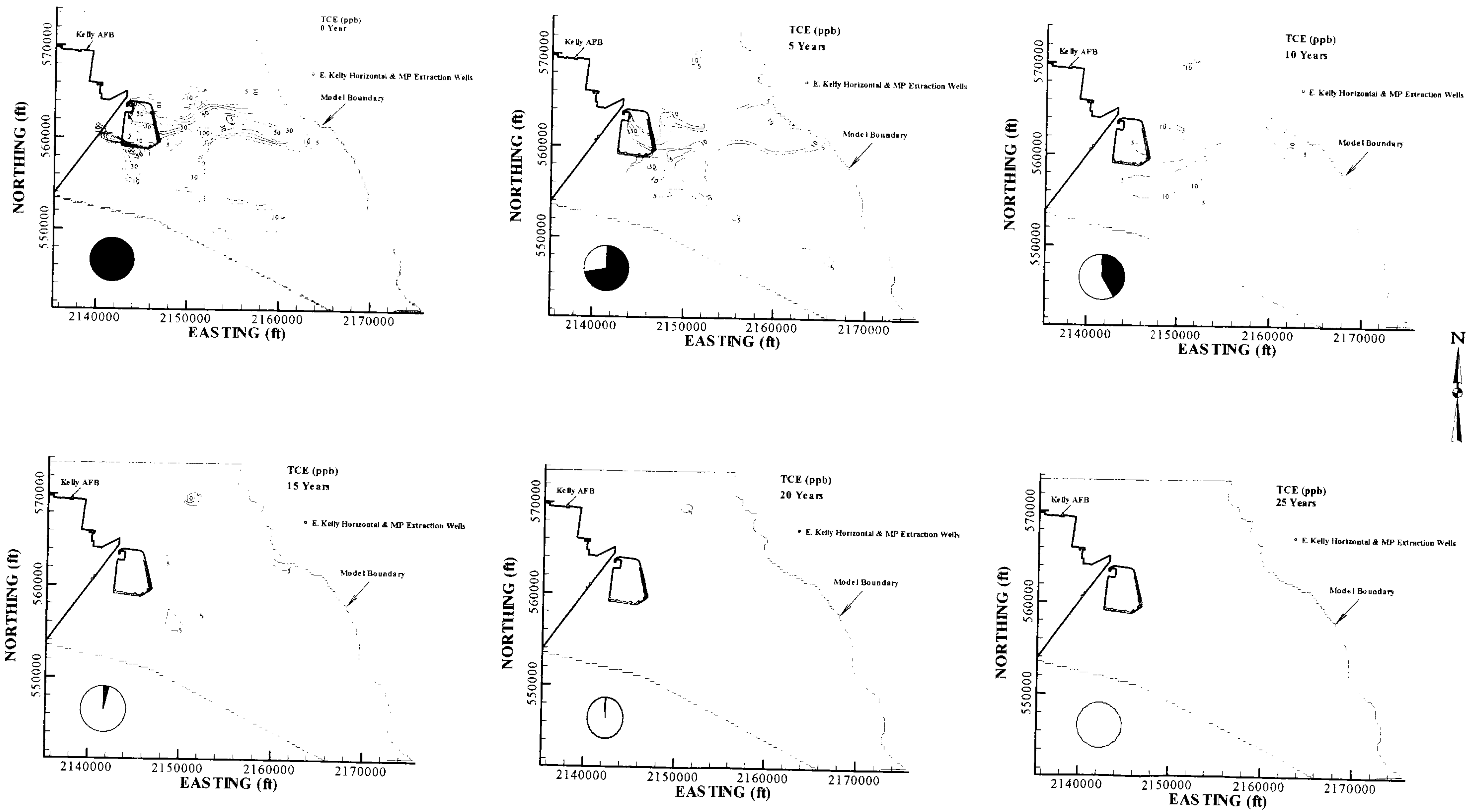


Figure 5-53 The Most Feasible Option D: Simulated TCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

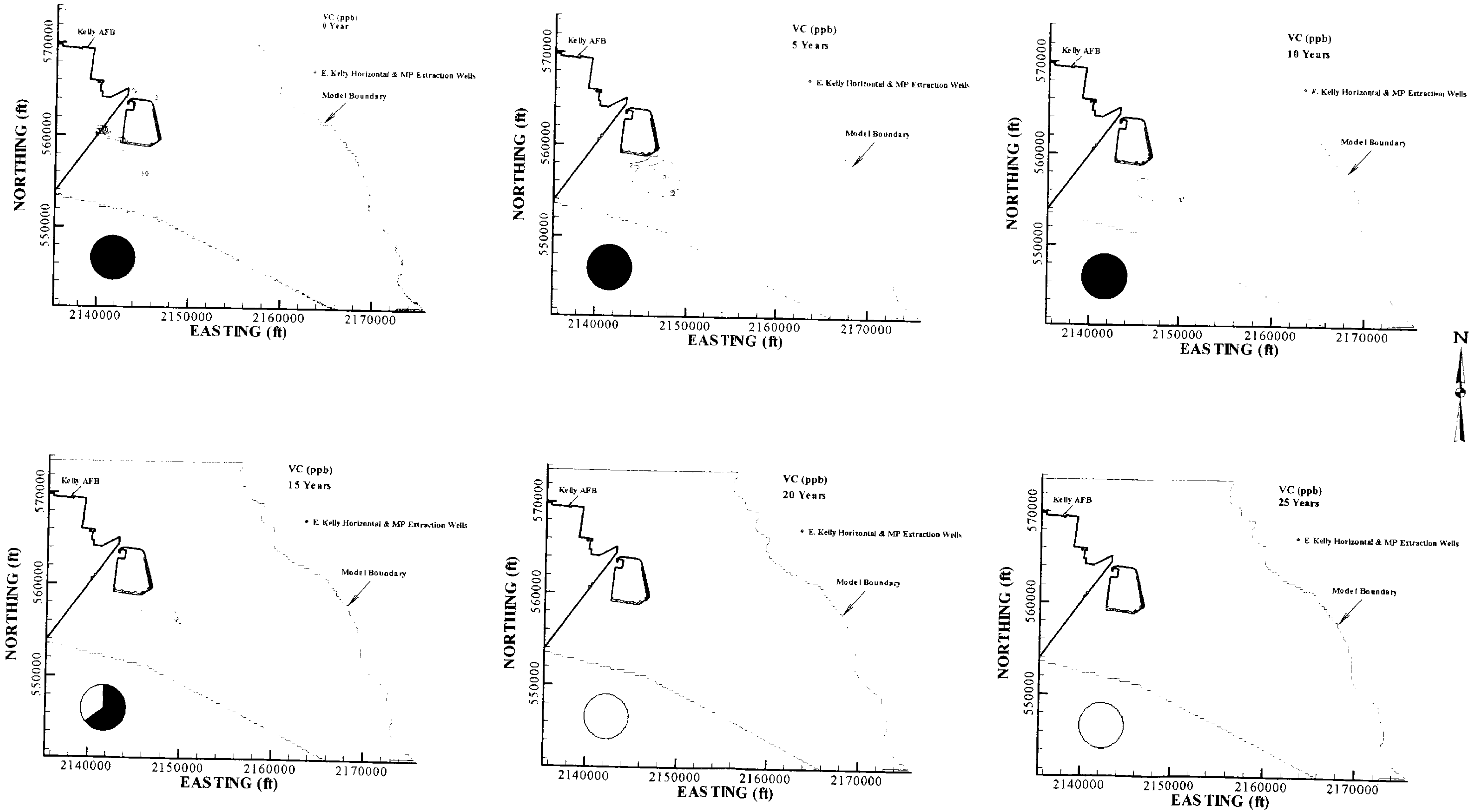


Figure 5-54 The Most Feasible Option D: Simulated VC Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

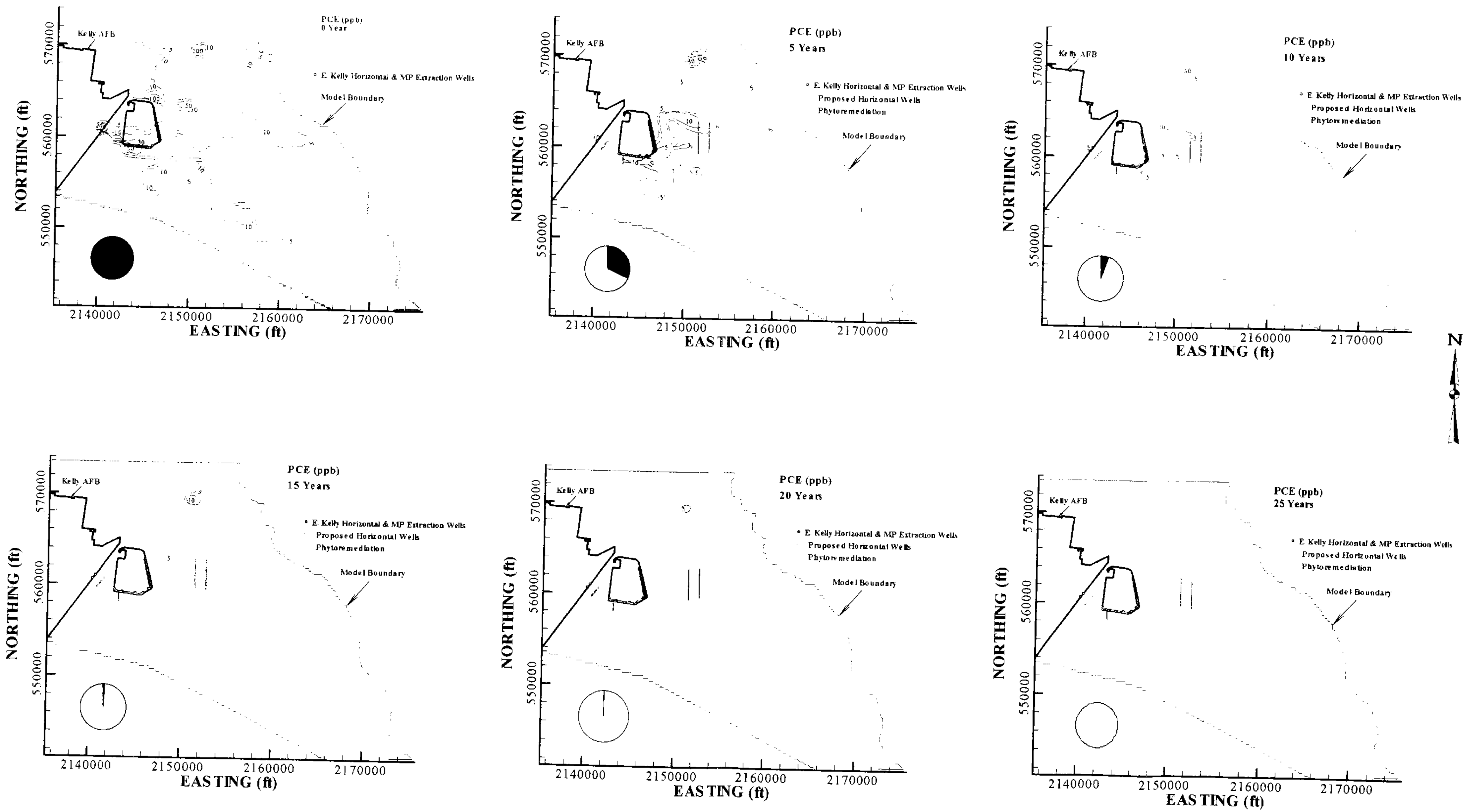


Figure 5-55 The Most Feasible Option B: Simulated PCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

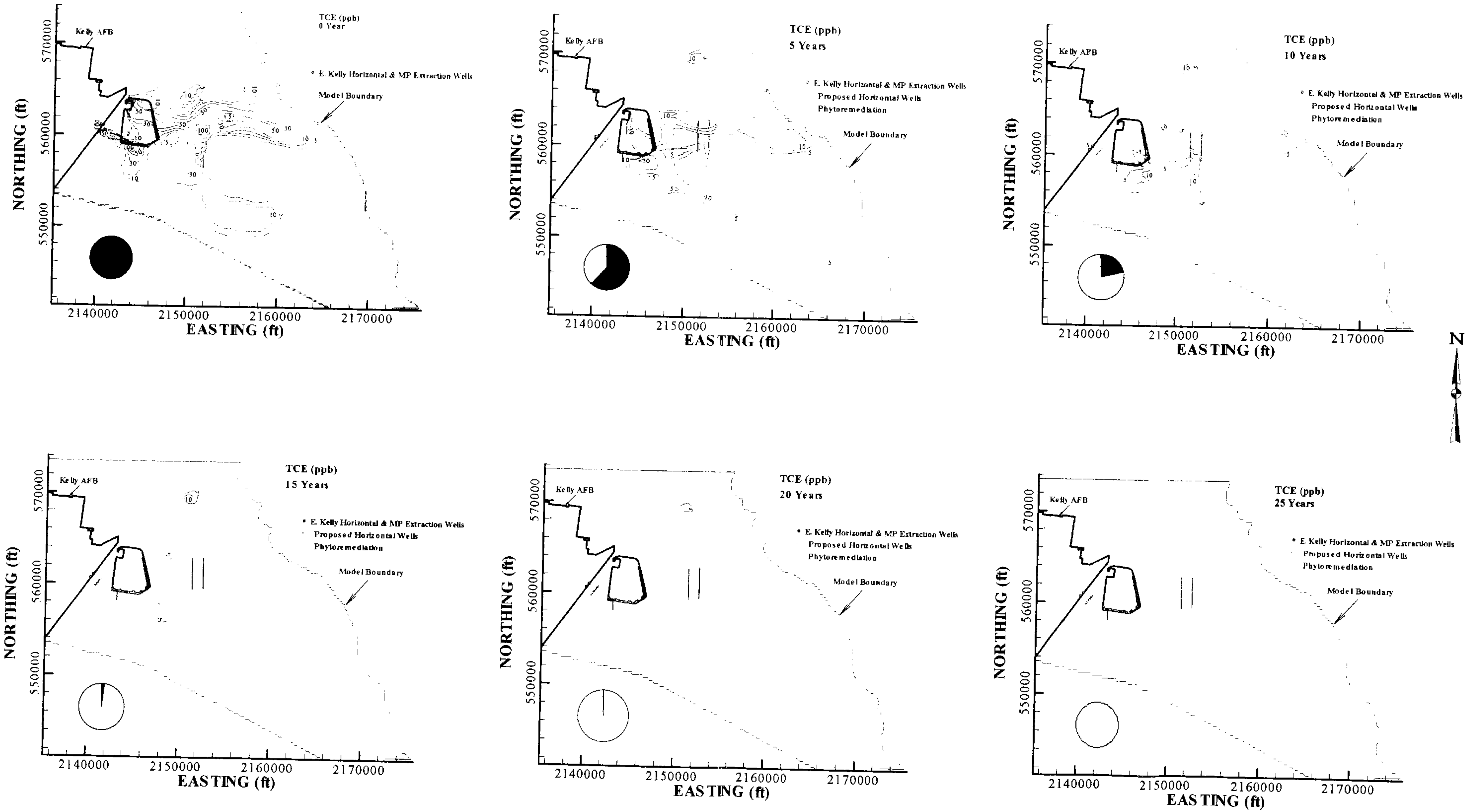


Figure 5-56 The Most Feasible Option B: Simulated TCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

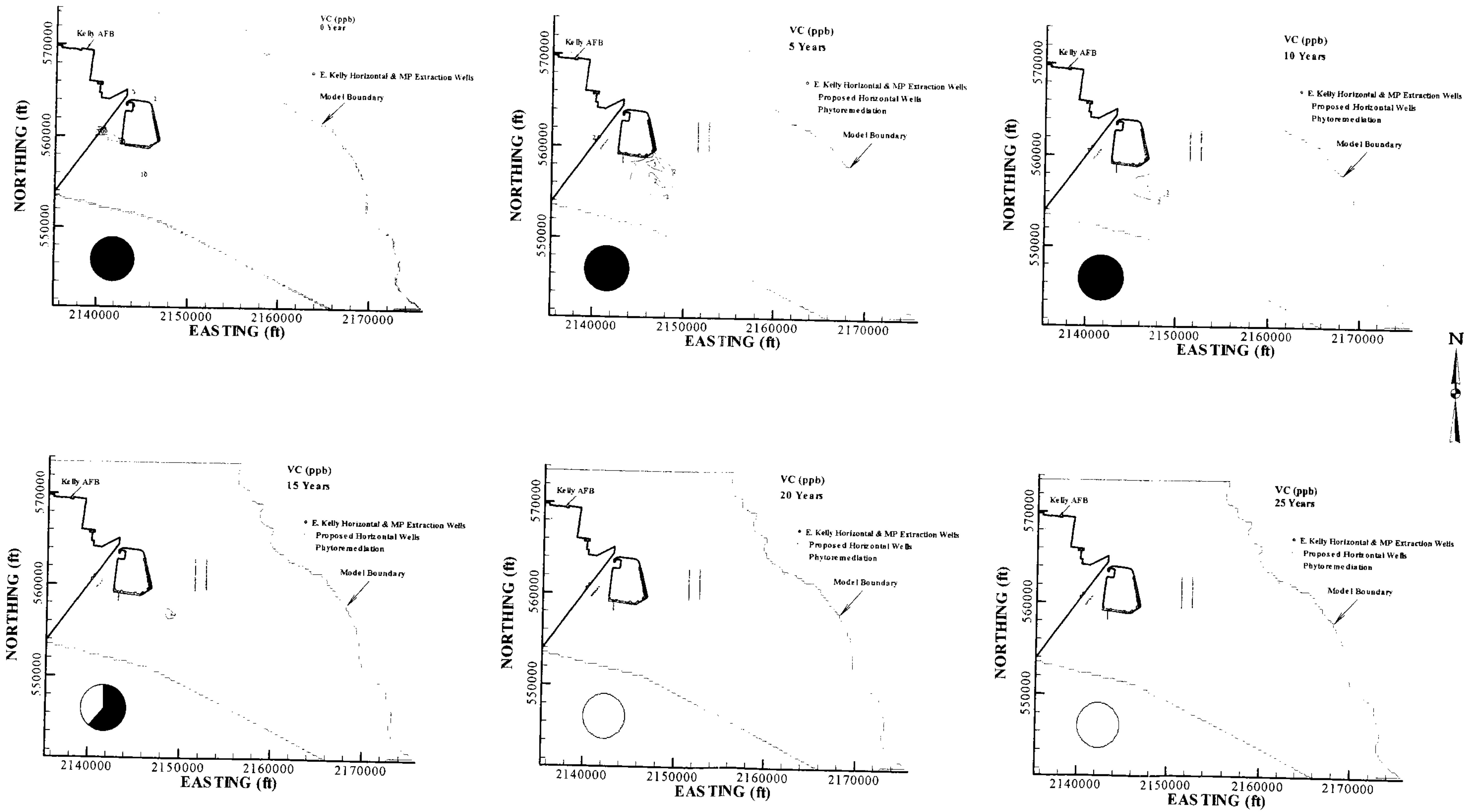


Figure 5-57 The Most Feasible Option B: Simulated VC Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

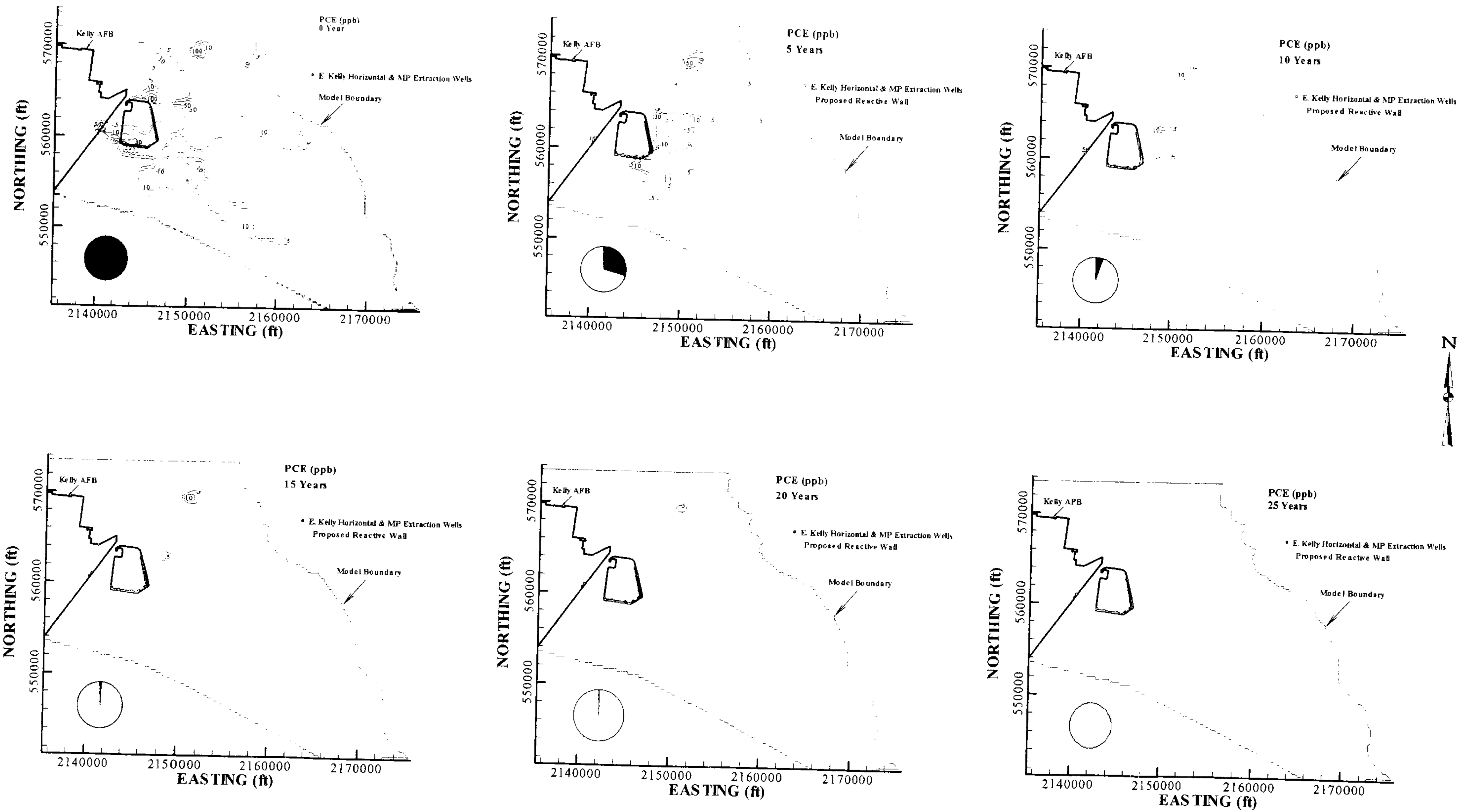


Figure 5-58 The Most Feasible Option F: Simulated PCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

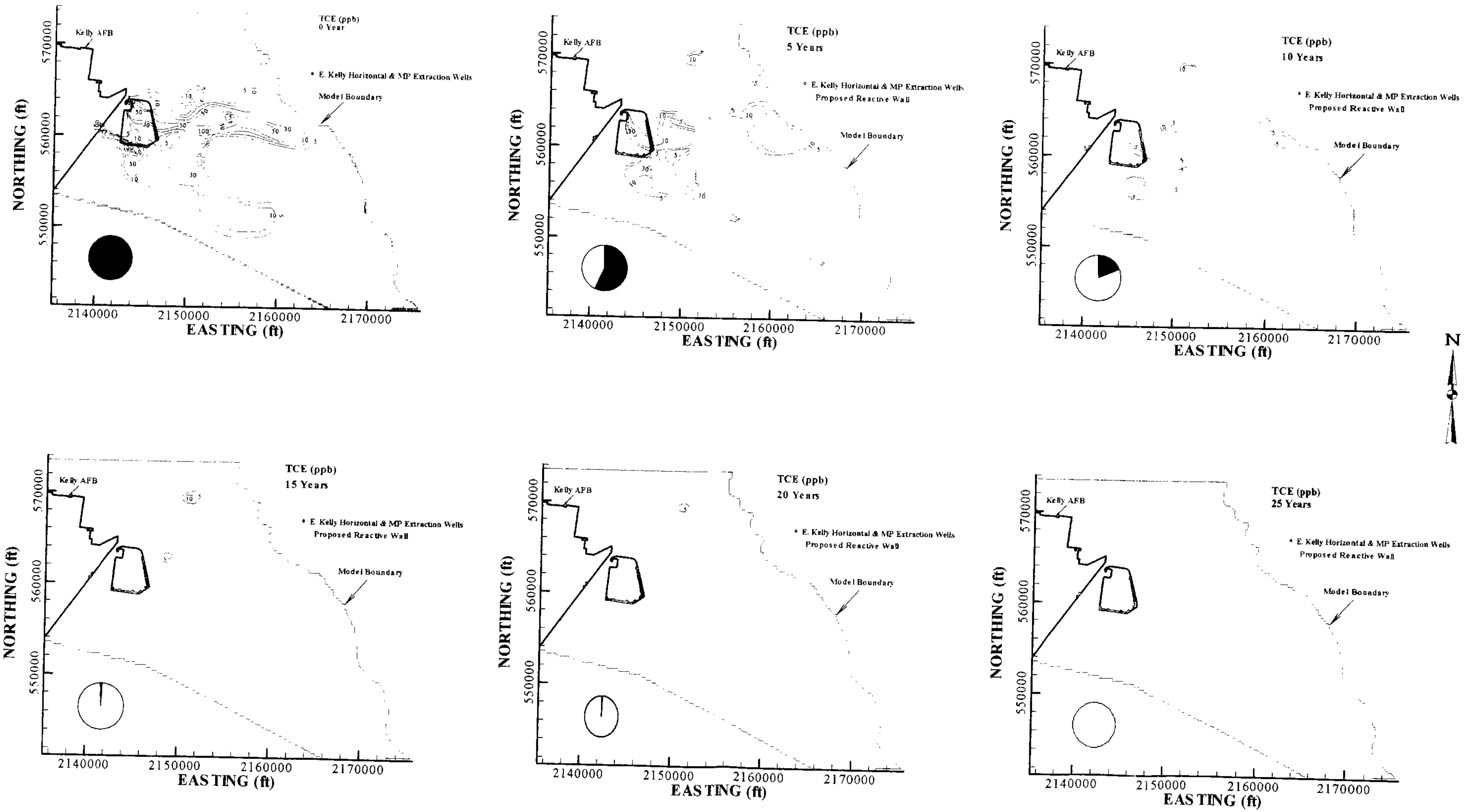


Figure 5-59 The Most Feasible Option F. Simulated TCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

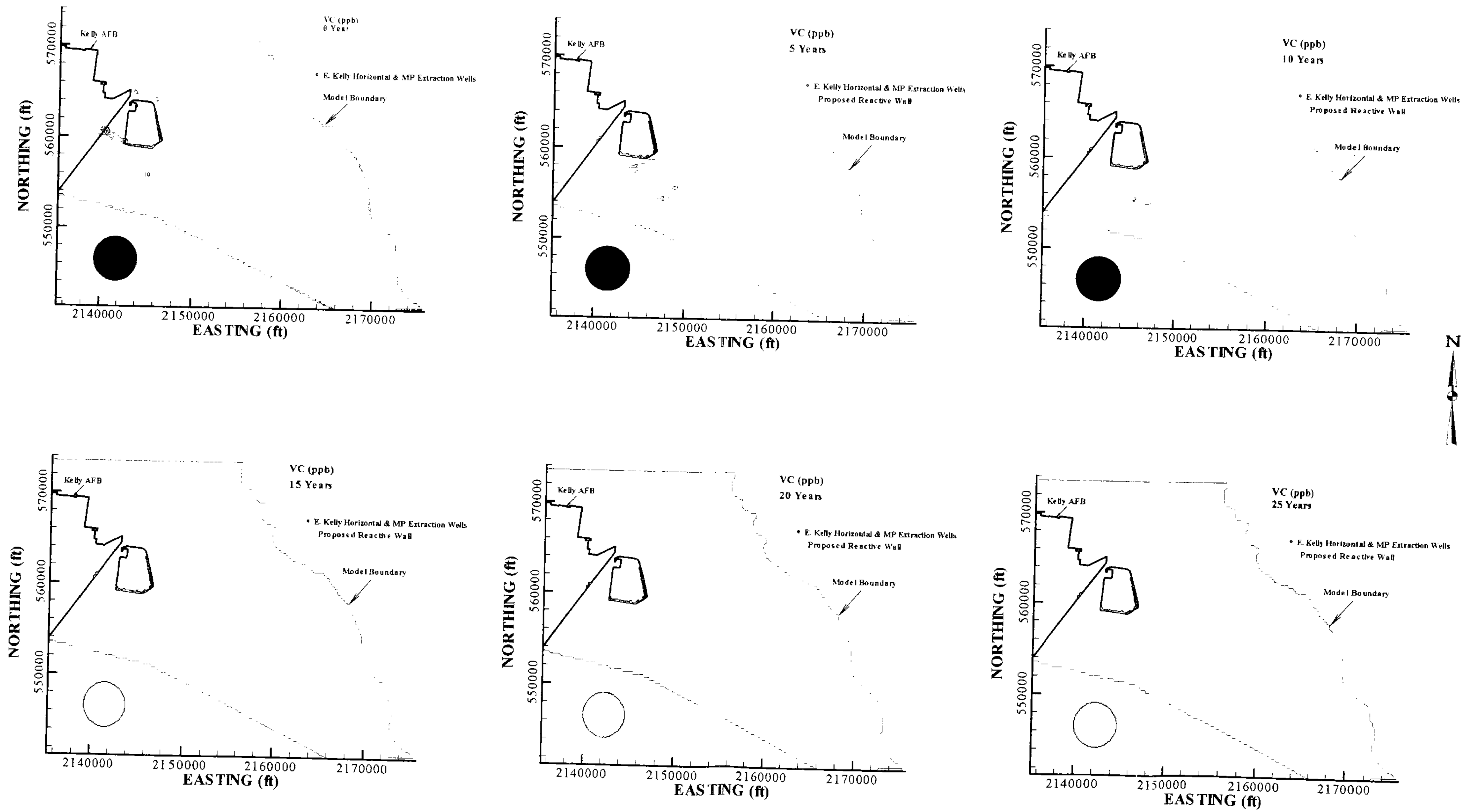


Figure 5-60 The Most Feasible Option F. Simulated VC Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

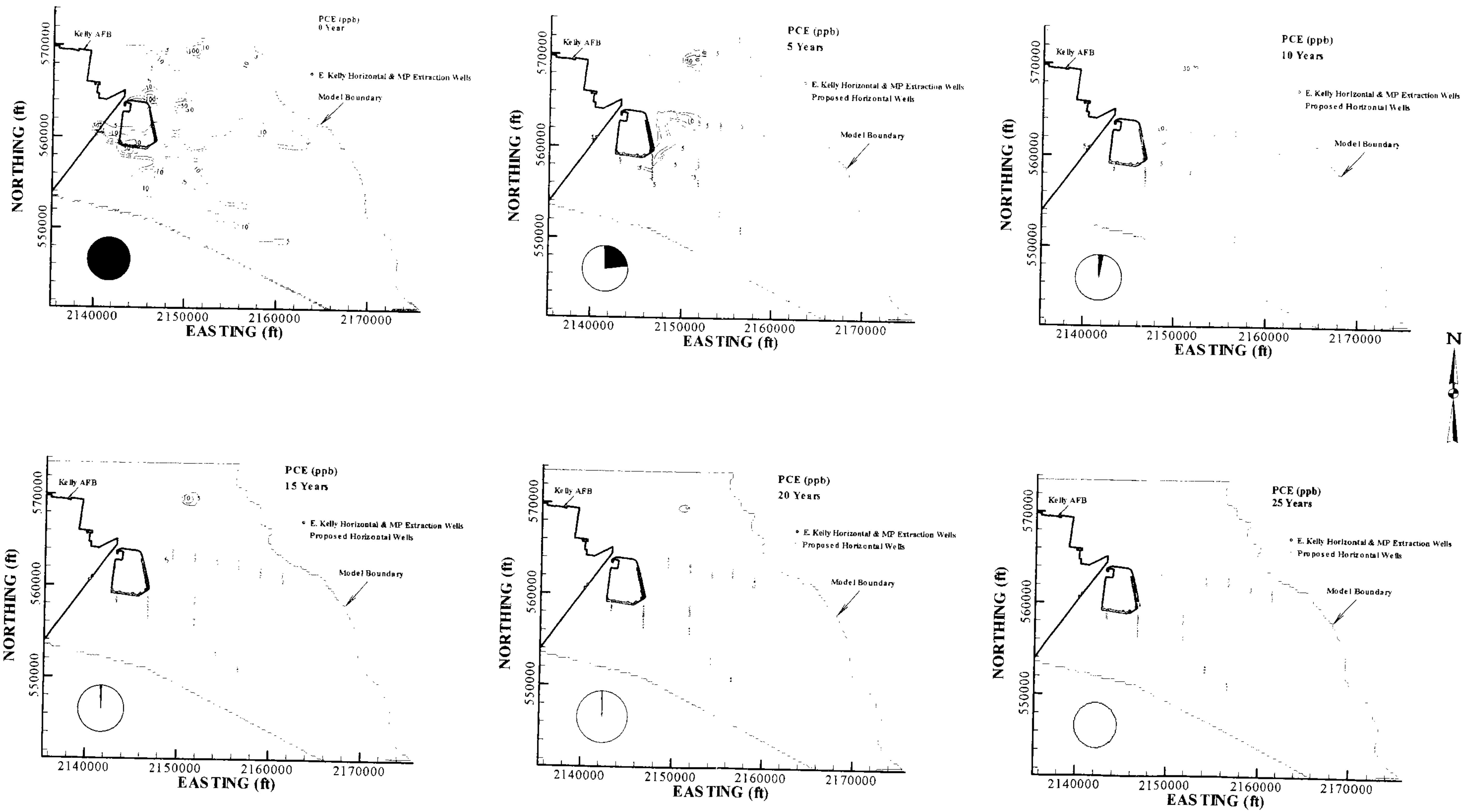


Figure 5-61 The Most Feasible Option A1. Simulated PCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

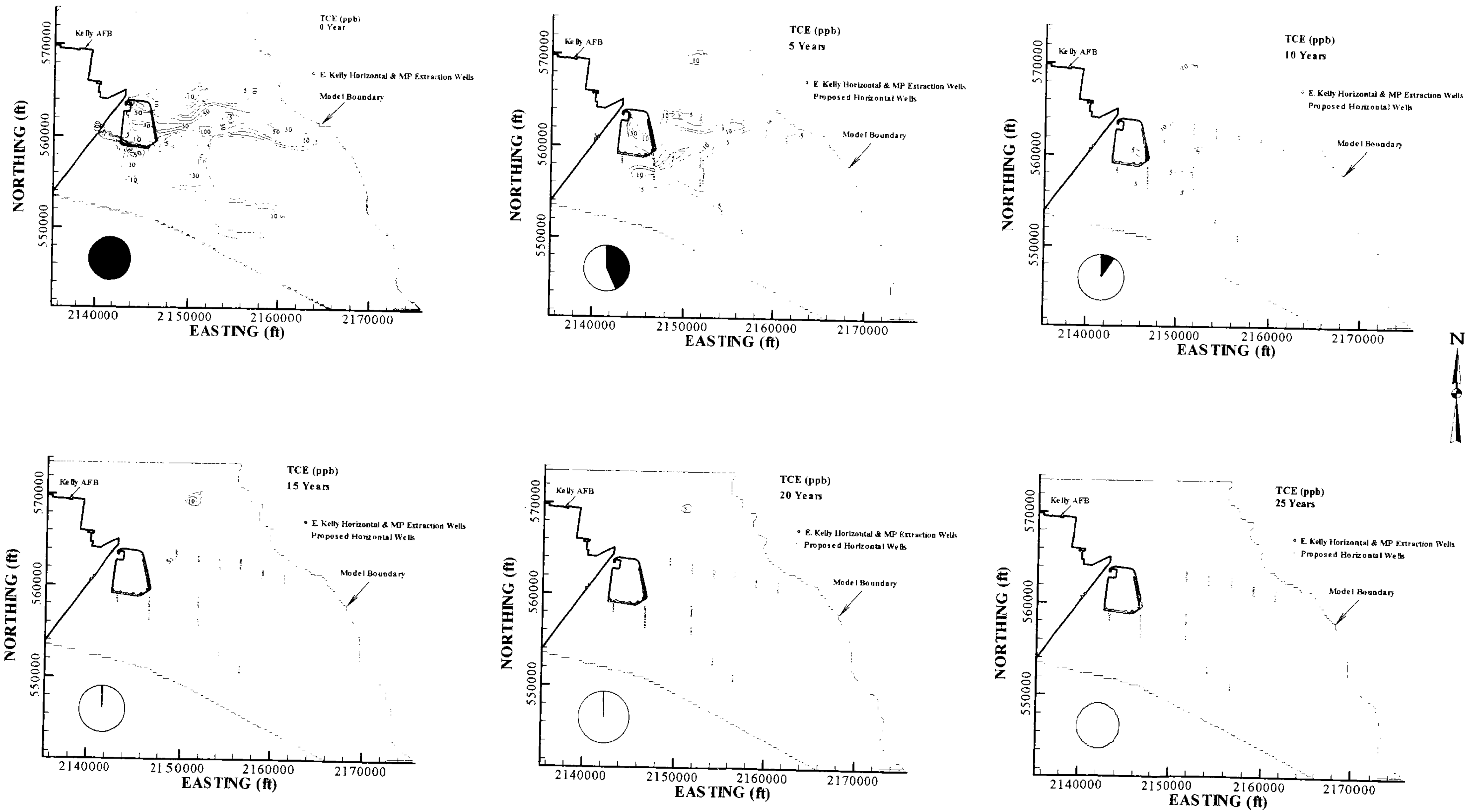


Figure 5-62 The Most Feasible Option A1: Simulated TCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

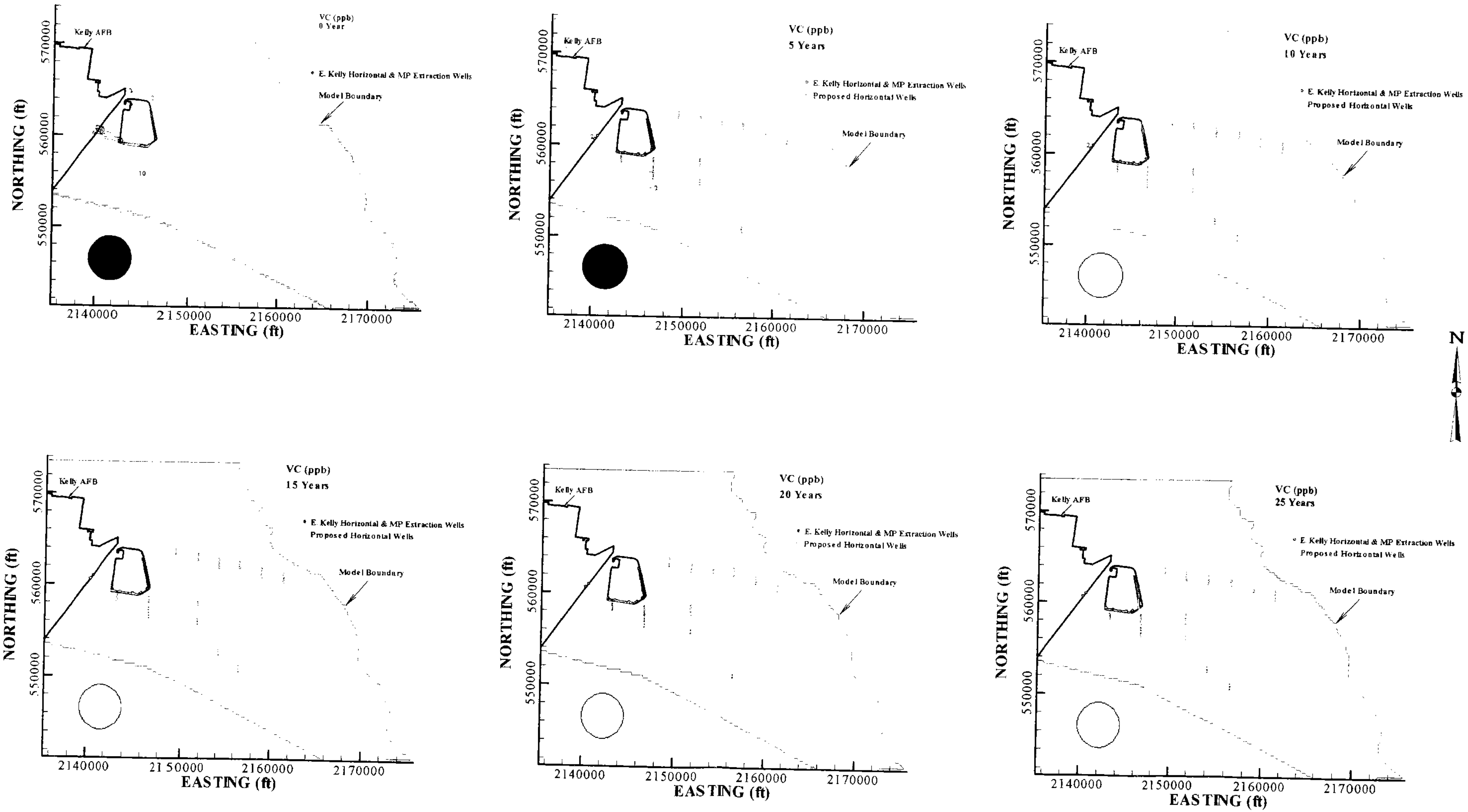


Figure 5-63 The Most Feasible Option A1: Simulated VC Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

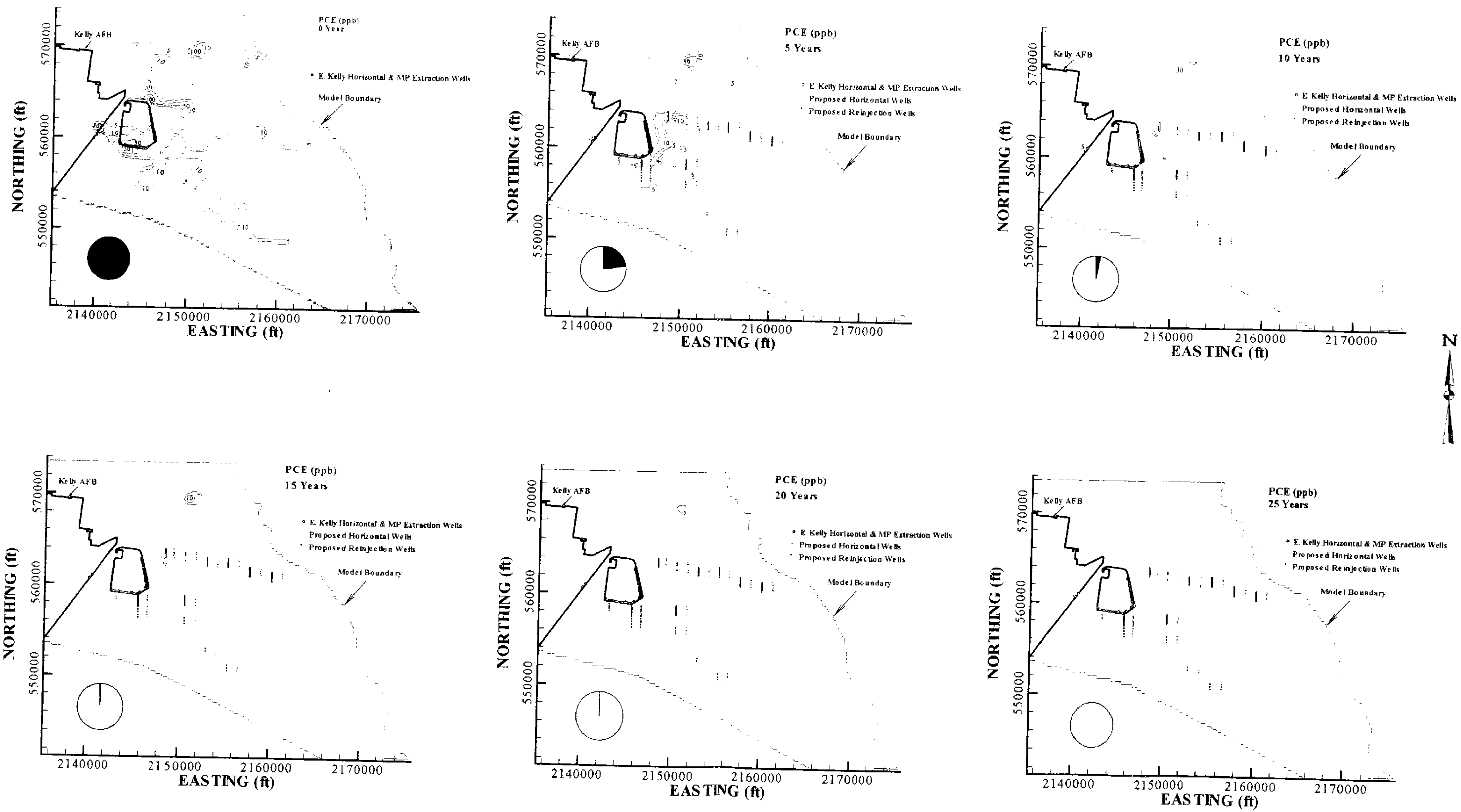


Figure 5-64 The Most Feasible Option C1: Simulated PCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

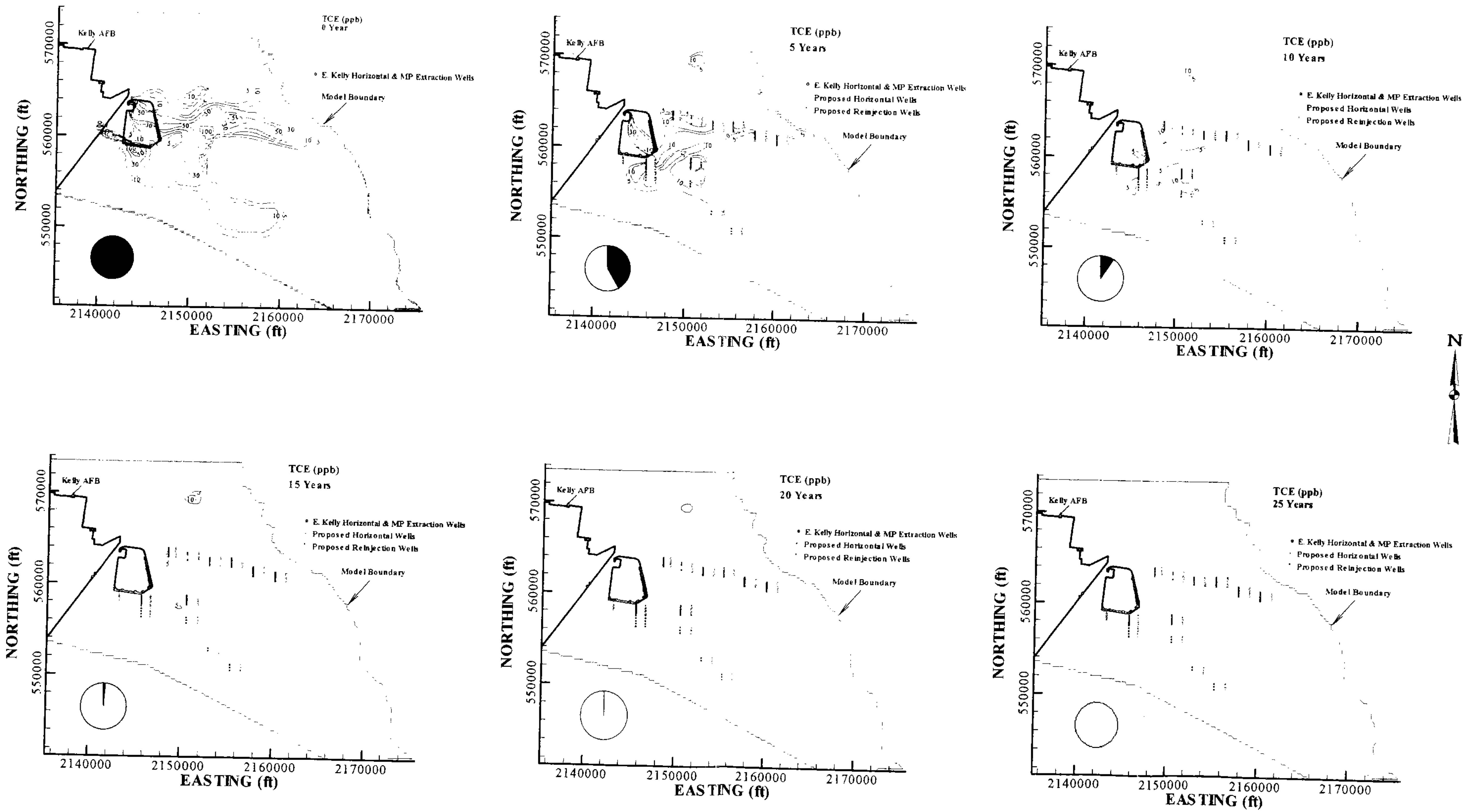


Figure 5-65 The Most Feasible Option C1: Simulated TCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

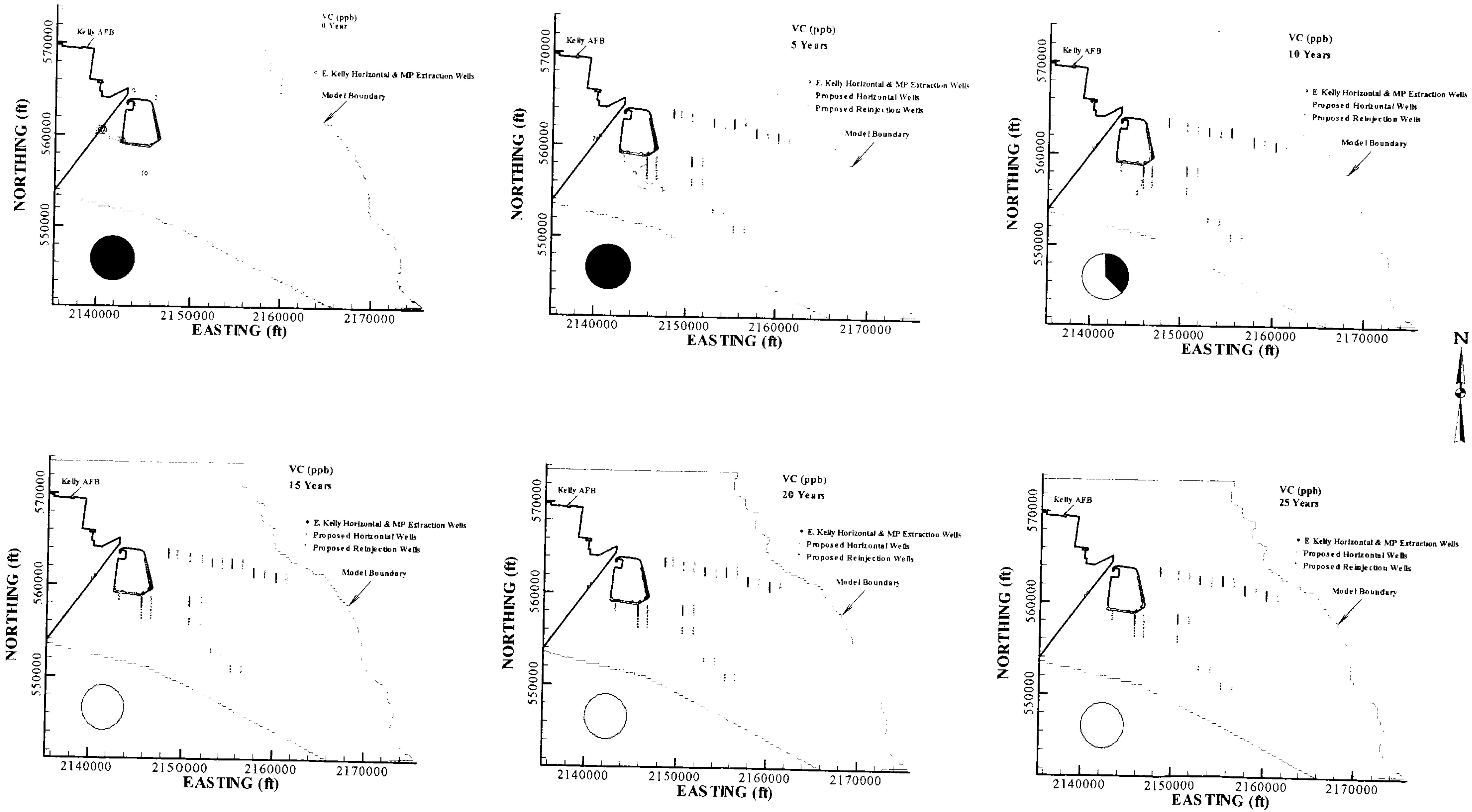


Figure 5-66 The Most Feasible Option C1: Simulated VC Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

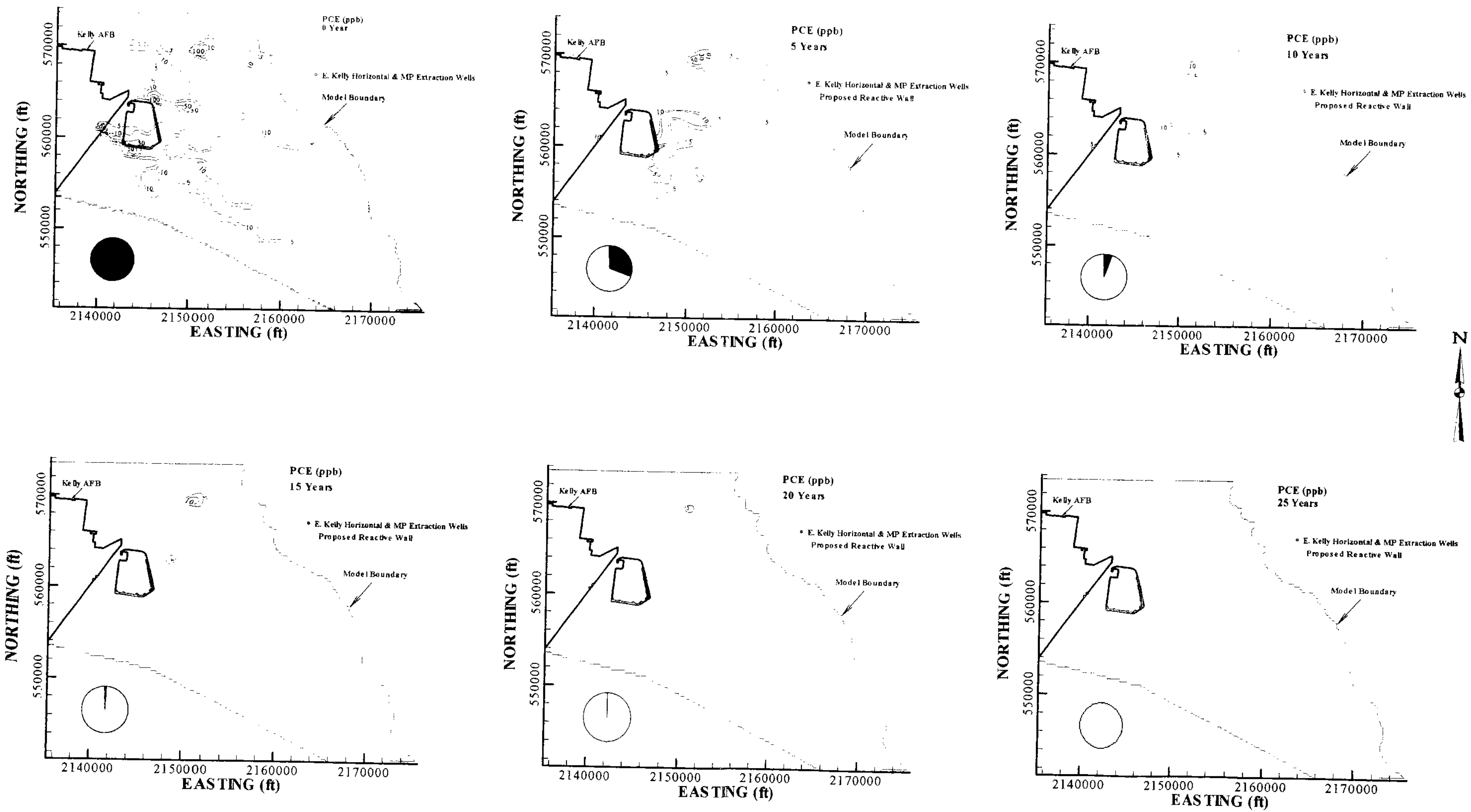


Figure 5-67 The Most Feasible Option E1: Simulated PCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

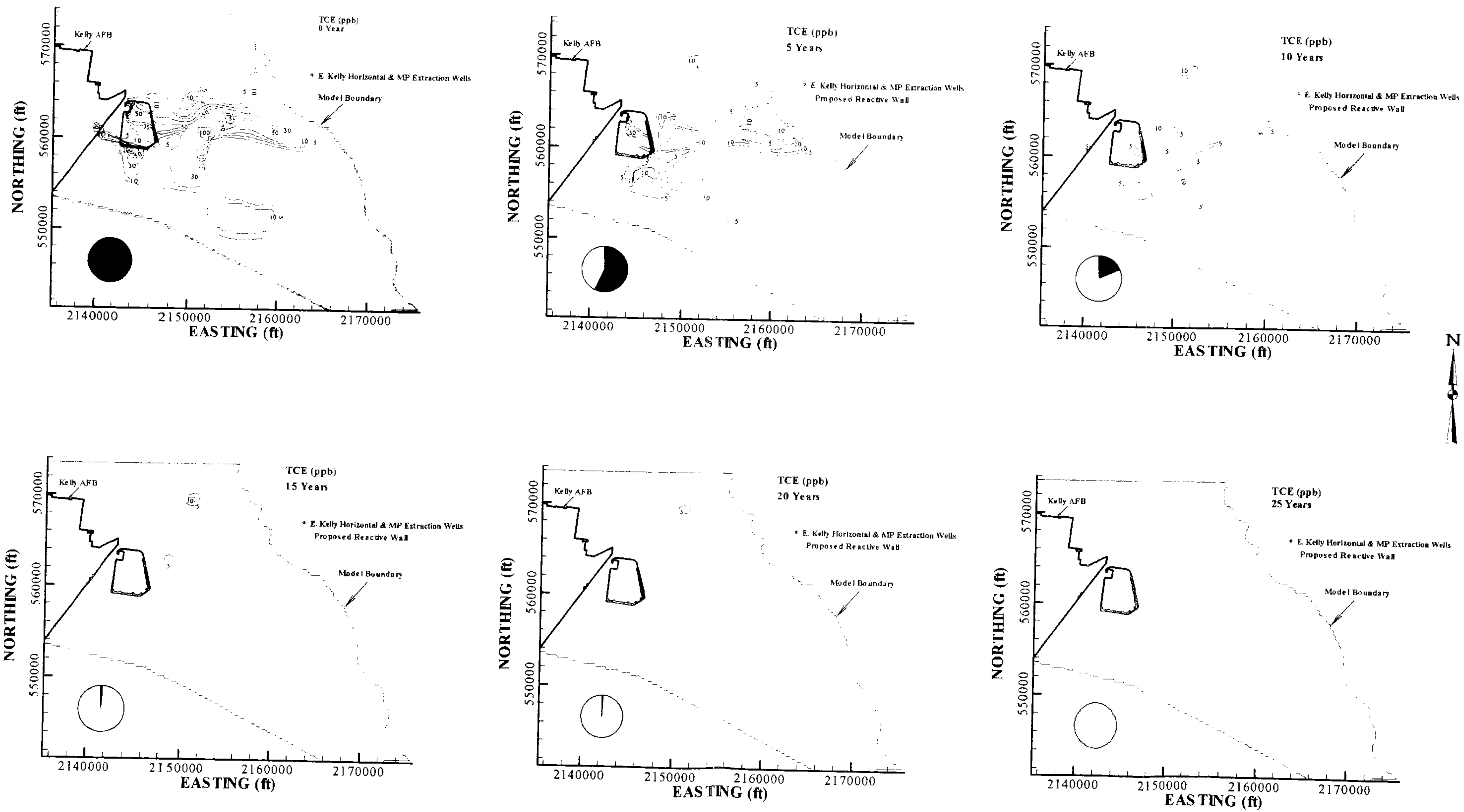


Figure 5-68 The Most Feasible Option E1: Simulated TCE Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

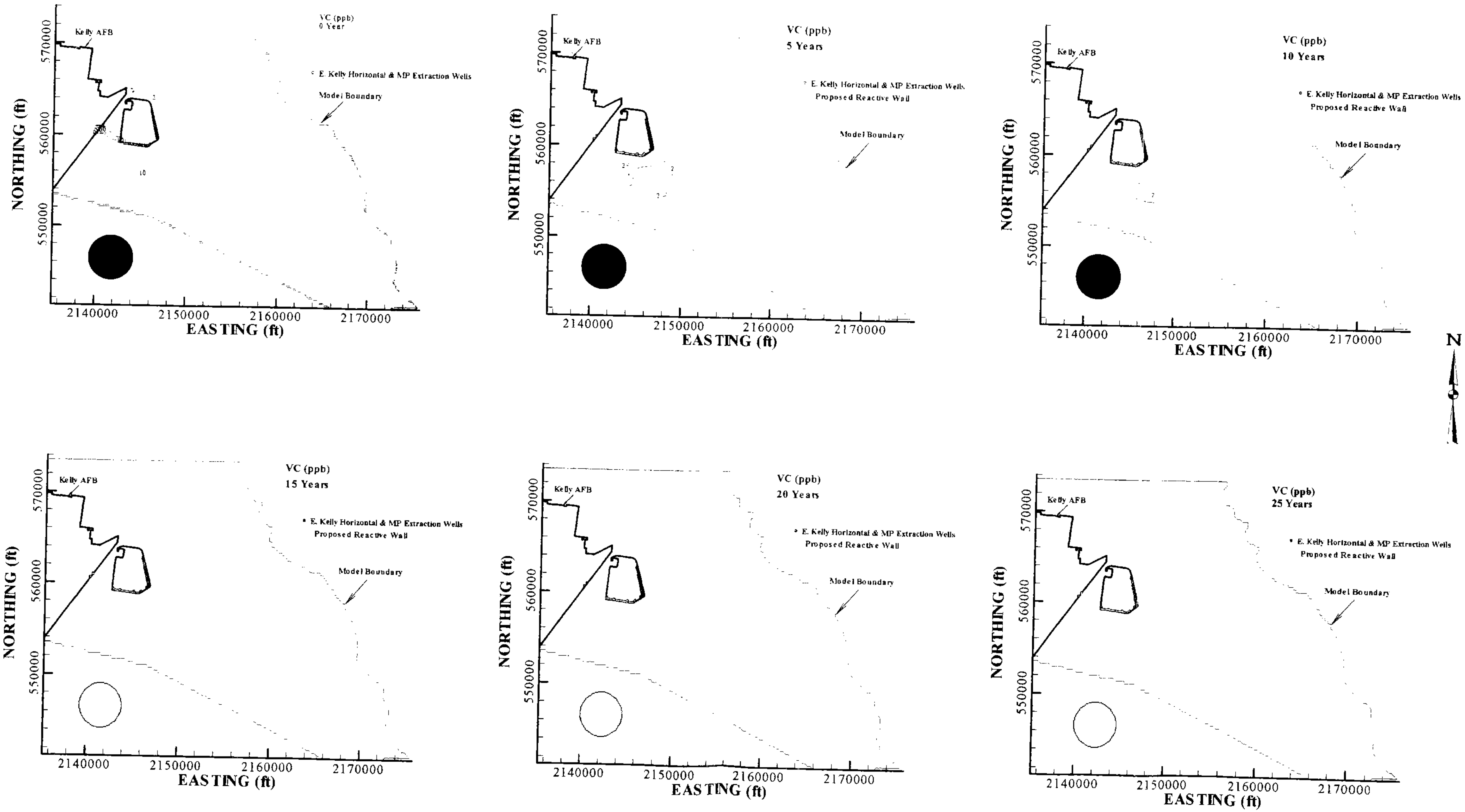


Figure 5-69 The Most Feasible Option E1: Simulated VC Contours (ppb) (Phase 2)

Note: Chart shows percent area of the FY 2000 plume that remains above MCL. A completely black or white circle represents a zero reduction and a 100% reduction in the plume area, respectively.

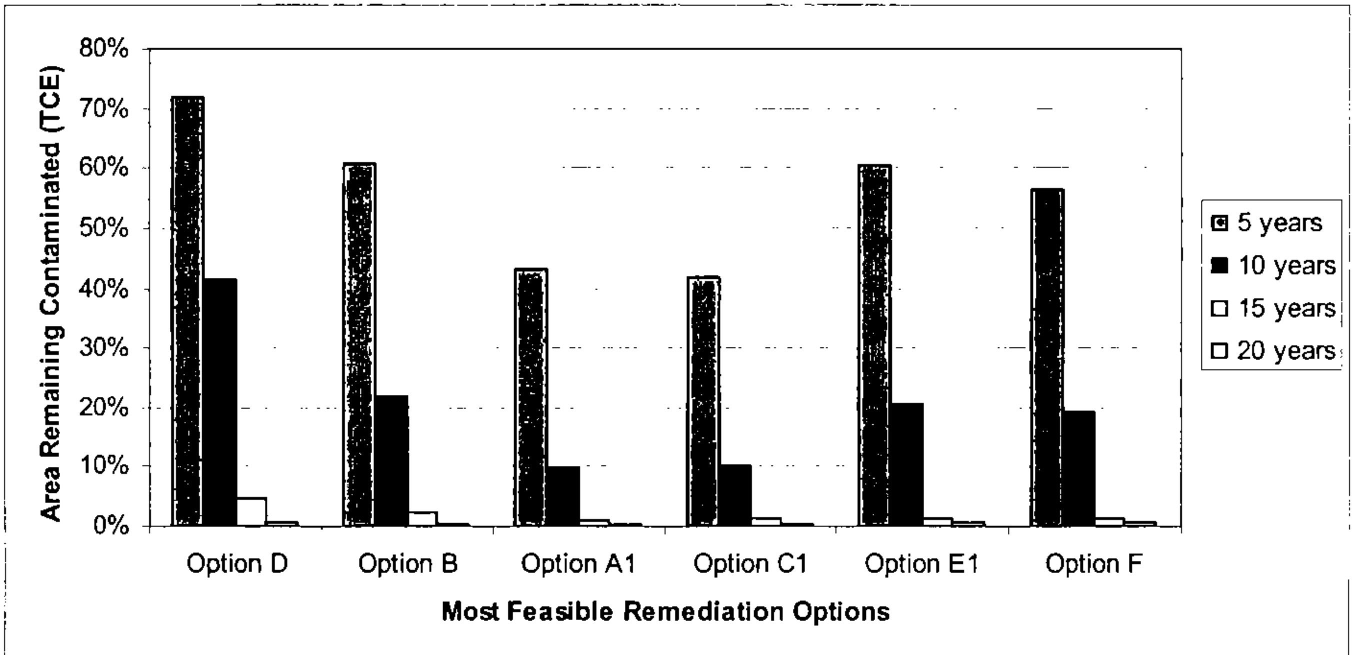


Figure 5-70 Comparison of Area Remaining TCE Contaminated among Most Feasible Remediation Options (Phase 2)

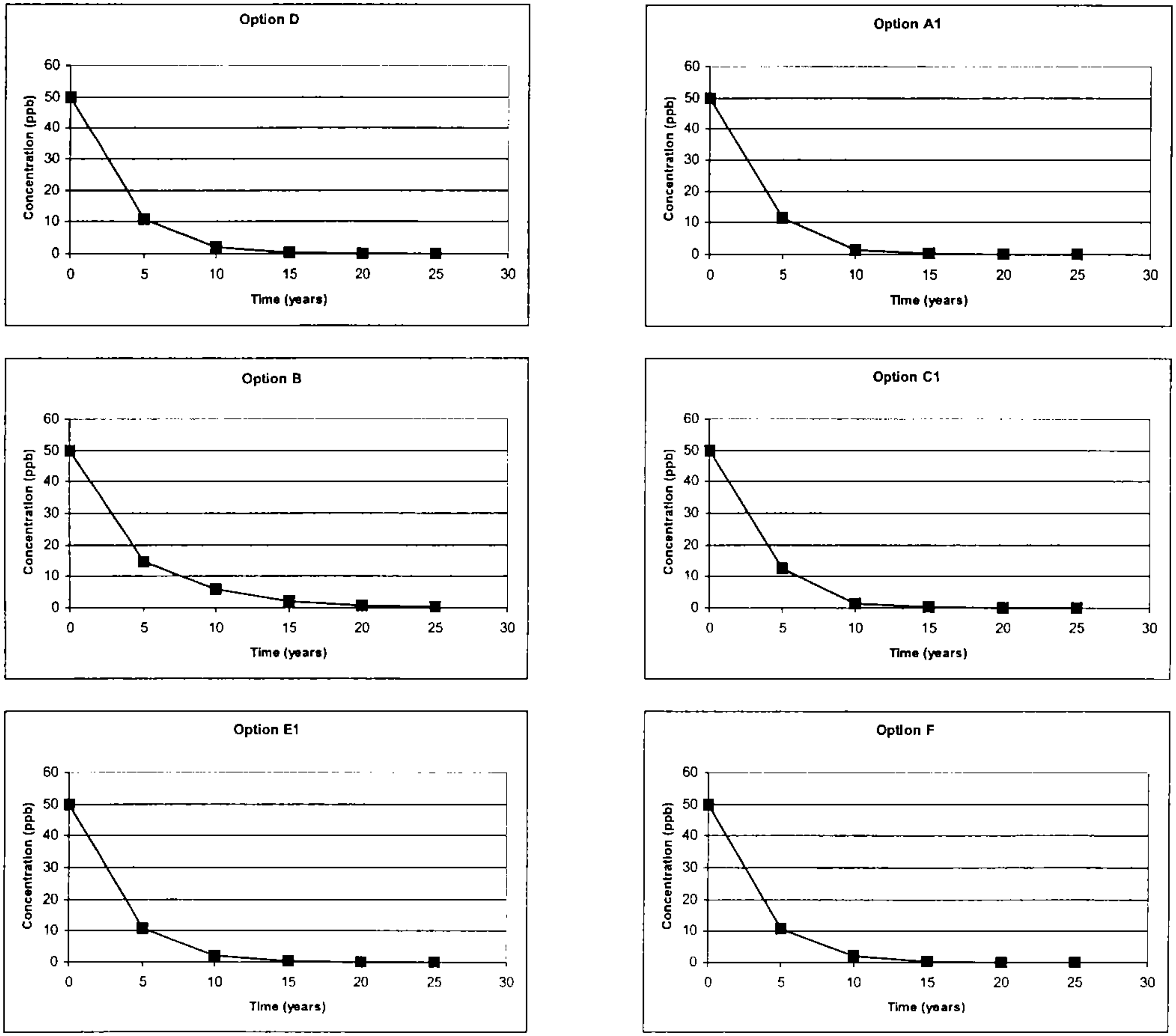


Figure 5-71 The Most Feasible Options—Maximum Concentration (ppb) Over Time for PCE at East Kelly (Phase 2)

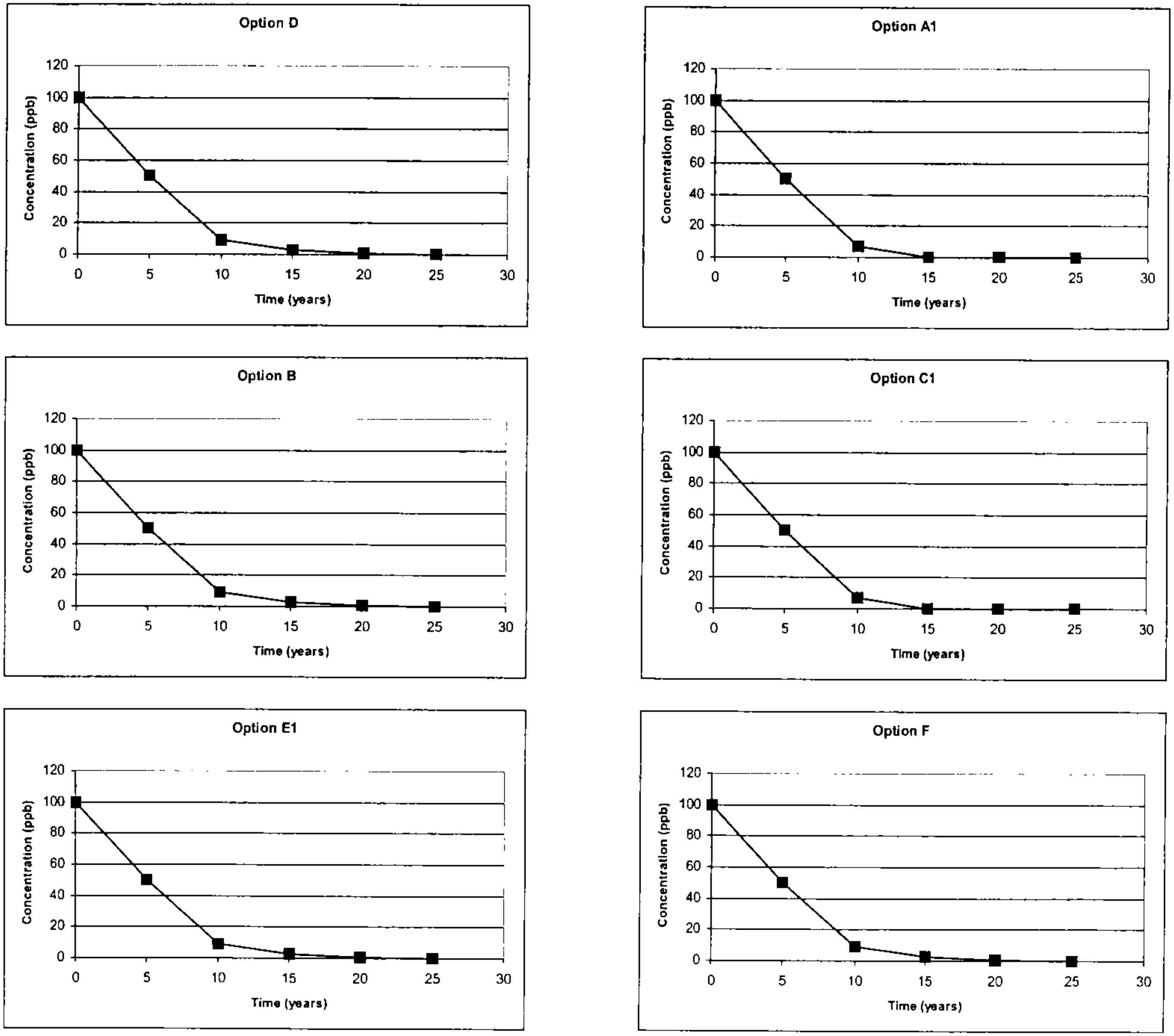


Figure 5-72 The Most Feasible Options—Maximum Concentration (ppb) Over Time for TCE at East Kelly (Phase 2)

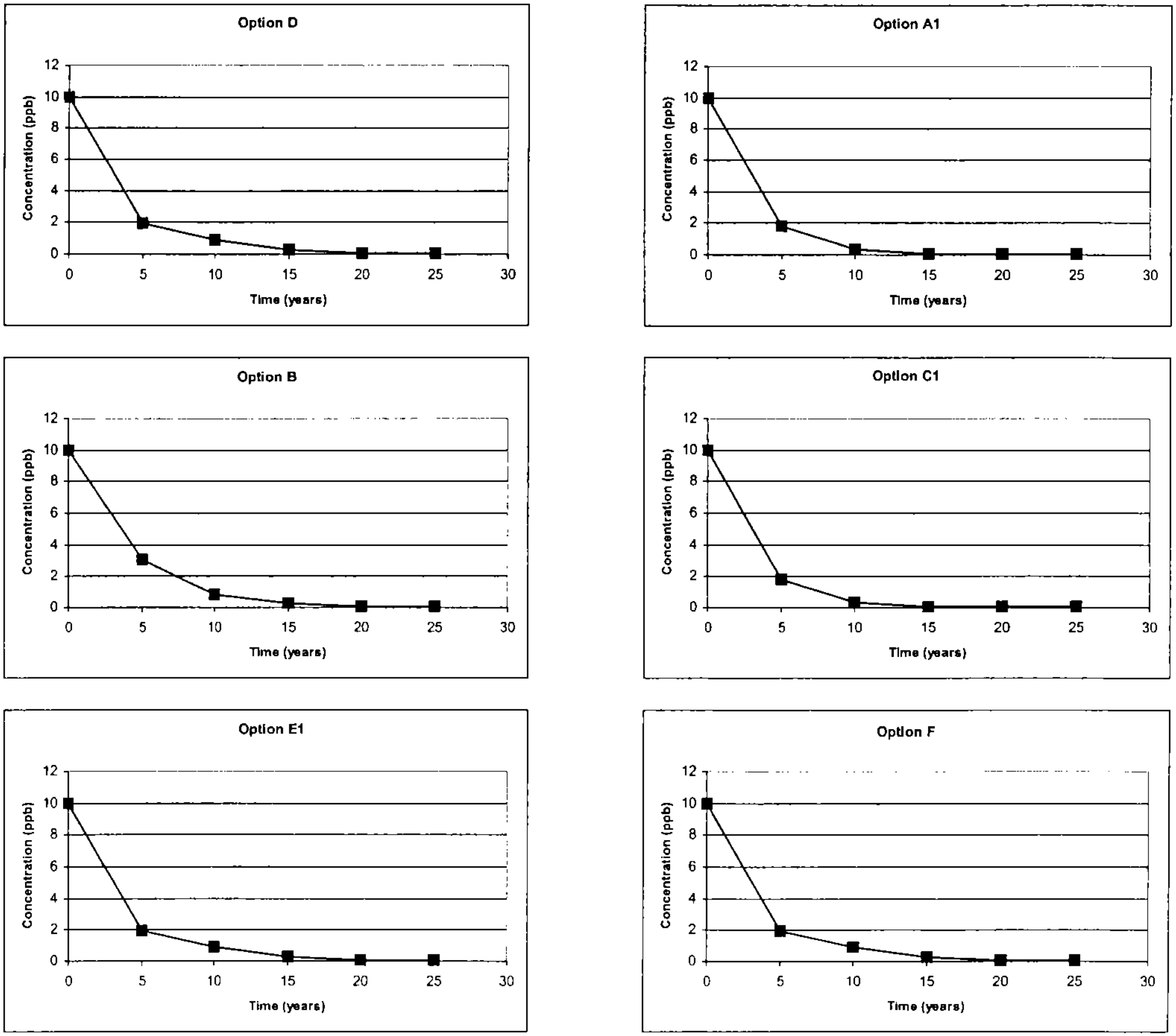


Figure 5-73 The Most Feasible Options—Maximum Concentration (ppb) Over Time for VC at East Kelly (Phase 2)

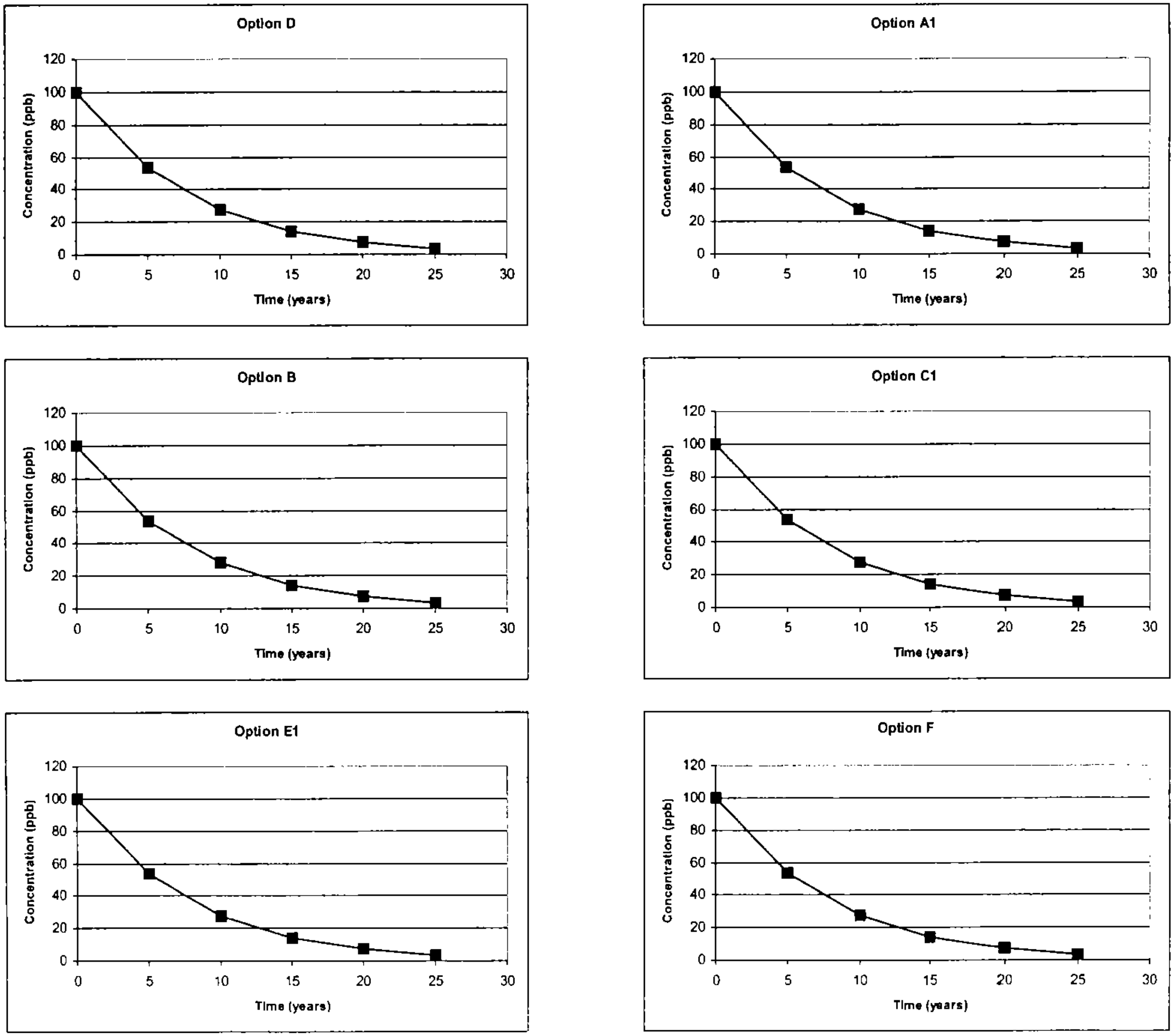


Figure 5-74 The Most Feasible Options—Maximum Concentration (ppb) Over Time for PCE Off Base (Phase 2)

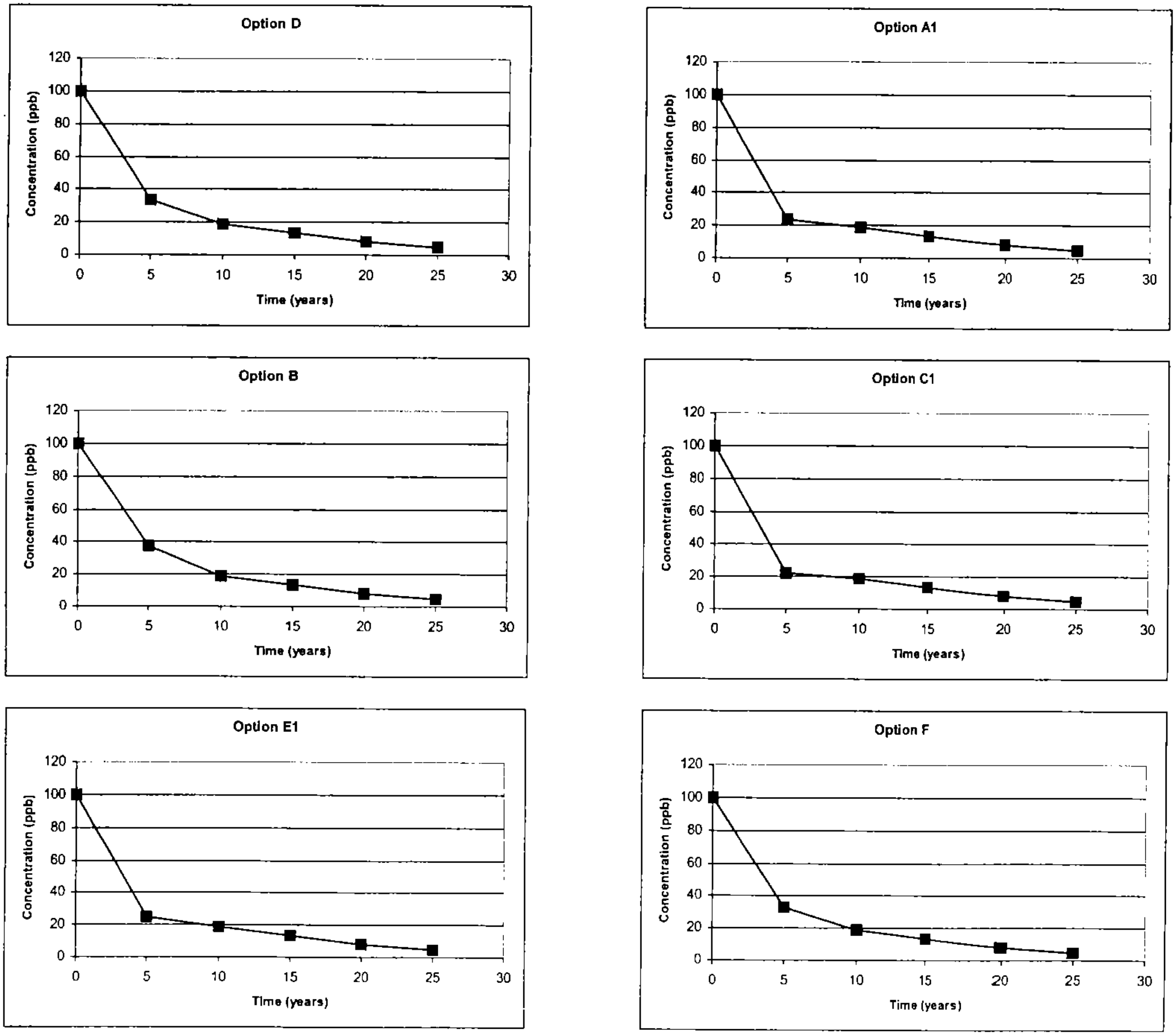


Figure 5-75 The Most Feasible Technical Options—Maximum Concentration (ppb) Over Time for TCE Off Base (Phase 2)

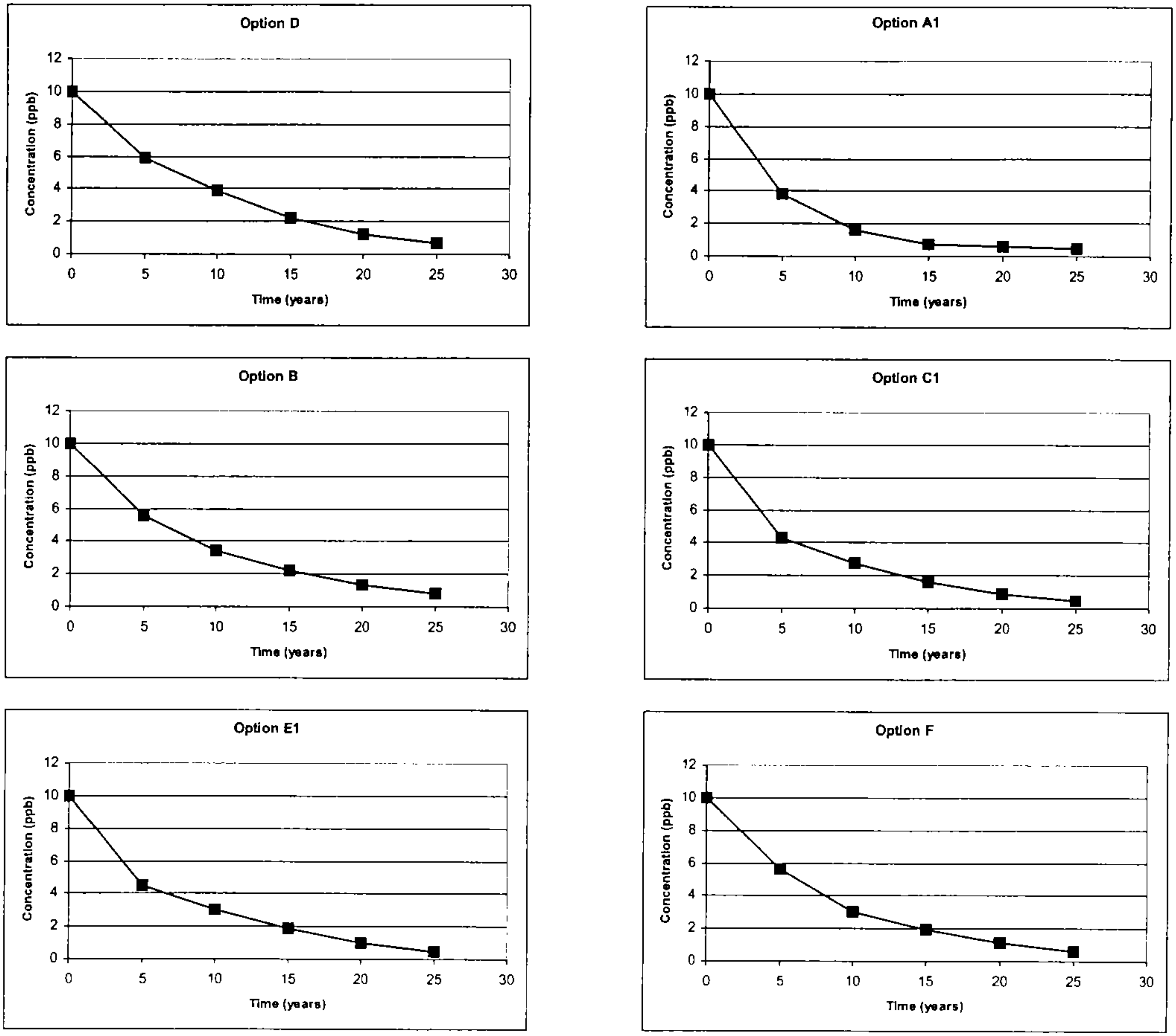


Figure 5-76 the Most Feasible Options —Maximum Concentration (ppb) Over Time for VC Off Base (Phase 2)

6.0 REFERENCE

Bureau of Economic Geology. 1983, Geologic Atlas of Texas San Antonio Sheet

Buscheck, T.E. and Alcantar C.M., 1995, Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation, in: Intrinsic Bioremediation [Pap in In Situ On-Site Bioreclam Symp] 3rd. Hinchee, R.E. et al. (Eds.). Batelle Press: Columbus, OH. pp 09-116.

Fathepure, B.Z. and Vogel T.M., 1991, Complete Degradation of Polychlorinated Hydrocarbons By A Two Stage Biofilm Reactor. Applied and Environmental Microbiology. 57:12 pp 3418-3422.

Freeedman, D.L. and Gossett, J.M.,1989, Biological Reductive Dechlorination of Tetrachloroethylene and Trichoroethylene to Ethylene Under Methanogenic Conditions. Applied and Environmental Microbiology. 55:0 pp 2144-2151

Gelhar, LW, Welty C, and Rehfeldt KR, 1992, A Critical Review of Data on Field-Scale Dispersion in Aquifers. Water Resour. Res. V. 29, no. 6, pp 1955-1974

GeoSyntec Consultants. 2000, Microcosm Report

HydroGeoLogic. 1998, "Model Results for Assessing the Effectiveness of Horizontal Wells for Ground-Water Capture at East Kelly", Letter Report

HydroGeoLogic. 1998, "MODFLOW-SURFACT, Version 2.0 User's Manual"

HydroGeoLogic. 1999a, "Basewide Ground-Water Flow Model for Kelly AFB, Texas", Draft Final

HydroGeoLogic. 1999b, "Evaluation of Remediation Alternatives at Site S-4, Kelly AFB Using a Ground-Water Flow and Transport Model", Draft Final

HydroGeoLogic. 2000a, "Evaluation of Remediation Alternatives at Site S-4, Kelly AFB Using a Ground-Water Flow and Transport Model", Final

HydroGeoLogic. 2000b, "Simulation of Extraction Systems for Zone 5 Plume at Kelly AFB, Texas Using Transport Zoom Models Developed from the Basewide Ground-Water Flow Model", Draft Final

Macarty, P.L. and Semprini, L., 1992, Engineering and Hydrogeological Problems Associated With in-Situ Treatment. In-Situ Bioremediation Symposium, Niagara-On-The-Lake.

USAF 2000. Draft Final RCRA Facility Investigation, Former Building 258 Solid Waste Management Unit, Kelly AFB, Texas. March

Vogel, T.M., Criddle, C.S. and Mccarty, P.L., 1987, Transformations of Halogenated Aiphatic Compounds. Environmental Science and Technology. 21:8, Pp722-736.

Wilson, J.T., et al., 1995, A Review of intrinsic Bioremediation of Trichlorethylene in Ground Water At Picatinny Arsenal, New Jersey, and St. Joseph, Michigan. in: Bioremediation of Hazardous Wastes. Research, Development, and Field Evaluations. USEPA. EPA/540/R-95/532

APPENDIX A

EVALUATION OF REMEDIATION ALTERNATIVES AT SITE MP

Site MP is located within the main Kelly IRP Zone 3. After a DNAPL pool was delineated, a slurry wall and a ground water recovery system was installed in 1999. Because of its historical and residual impact on ground water off-base, Site MP was treated as a continuing PCE source for Phase 1 Zone 4 off-base transport simulation. A flow and transport zoom model was developed at Site MP for adequately simulating existing plume conditions at site for use in evaluating remediation alternatives, and for the determination of a PCE source term for Phase 2 Zone 4 off-base transport simulation.

A.1 MODEL FRAMEWORK

Figure A-1 displays the MP zoom model numerical grid embedded within the expanded basewide model and superimposed on a base boundary map. The MP zoom model has dimensions of 15,300 feet (easting) by 11,700 feet (northing) covering an area of 6.4 square miles, or approximately one-fifth of the expanded basewide model. The numerical mesh of the MP zoom model has a uniform grid spacing of 300-ft, 100-ft and 50-ft. The refined 50 ft grid spacing is in the vicinity of the MP remediation system. The numerical grid consists of 100 rows and 112 columns of cells for a total of 11,200 grid cells in each of the four model layers.

An approximately 300 ft by 300 ft slurry wall was installed at Site MP in 1999. The slurry wall was set into depth of the Navarro Clay for complete containment of the contaminant sources. For model simulation, the slurry wall was entered as a horizontal flow barrier package. Figure A-2 shows the slurry wall location in the MP zoom model domain.

A detailed examination of borelog information and extracted K-field of model layer 4 in the area to the east of the slurry wall and along the base boundary show K characteristics of embedded silt and clay at that locations. Accordingly, a low-K block (varying between 5 to 100 ft/day) was inserted into the model layer 4. Figure A-2 also shows contour maps of K field in the zoomed-in area of the MP model domain.

A.2 SIMULATED HYDRAULIC HEADS

Figure A-3 shows simulated hydraulic heads in a zoomed-in area of the MP model domain under both ambient and pumping conditions. A 2-ft head difference was built up around the slurry wall in the ambient case, while the difference was about 3 ft for the pumping case. Approximately 2 to 4 ft drawdown appears around two MP pumping wells at the April 1999 extraction rates.

Table A-1 summarizes the ground-water fluxes into and out of the MP Zoom model domain under both ambient and pumping conditions The model was solved for steady-state flow with mass balance errors ranging of 0 to 0.02 %.

Table A-1
Ground-Water Fluxes (ft^3/day) Calculated by the MP Zoom Model

MP Zoom Model		Recharge	Well	Model Boundary	Total Flux
Ambient	In	117660	0	417590	535250
	Out	0	0	-535150	-535150
	Net	117660	0	-117560	100
Mass Balance Error					0.02%
Pumping	In	117660	0	424790	542450
	Out	0	-13475	-528950	-542425
	Net	117660	-13475	-1041600	25
Mass Balance Error					0.00%

A.3 ASSUMPTIONS FOR TRANSPORT SIMULATION

For determination of parameters of model package for transport simulation, following assumptions were made:

- The current source control system at Site MP consists of a slurry wall and hydraulic containment wells. The slurry wall surrounding the entire source areas (DNAPL pool) was installed into depth of Navarro Clay. The hydraulic containment wells are operated with optimized extraction rates. The slurry wall and associated ground-water recovery wells effectively isolate the contaminant source area (i.e. no on-going source of contamination is occurring from within the slurry wall).

- No up-gradient source of ground-water contamination involved.

- As suggested by historical data, no soil contamination or DNAPL outside the slurry wall and within the site boundary is providing an on-going source of ground-water contamination.

Based on the above assumptions, a continuing source term for model input is not warranted. Existing plumes shown in Figures A-4 and A-5 were used as initial contaminant mass distributions of PCE, TCE, DCE, and VC for model input. The contour maps were developed based on a set of AutoCAD drawing provided by SAIC from 1999 RFI and Semi-Annual Ground-Water Compliance sampling results (USAF, 2000). Data points within the slurry wall were not included in the contouring. The contour lines were extended to the east boundary of the Union Pacific Railroad tracks.

Figures A-4 and A-5 also show depletion of PCE and TCE, and increasing of DCE and VC down gradient from the base boundary. This pattern closely resembles plume configuration maps at Site S-4, suggesting that similar geochemical environment to the Site S-4 exists at Site MP, that is more anaerobic than that of broad area of the Zone 4 off-base model domain. Therefore, biodegradation rates of 4 years, 4 years, 3 years, and 2 years for PCE, TCE, DCE, and VC, respectively, developed for the Site S-4 transport simulation were used for the MP zoom modeling (see Section 3-3, Table 3-2).

Same aquifer properties and adsorption values developed for Zone 4 off-base model were also incorporated into the MP zoom model.

A.4 SIMULATION RESULTS OF REMEDIATION ALTERNATIVES

Four potential remediation alternatives were simulated using the refined MP zoom model and input parameters developed in the previous sections. All four remediation alternatives have the existing slurry wall in place. No action alternative does not include two MP pumping wells, corresponding to an ambient condition. Existing system alternative has two MP extraction wells pumping at proposed extraction rates of 35 gpm each. Existing system with additional well alternative adds a well SS040RW134 at extraction rate of 3 gpm. Existing system with enhanced biotreatment alternative inserts a bio-block to the elevated concentration area to the northeast of the slurry wall. Degradation rates within the bio-block are half-lives of 0.001 year for all four compounds.

The goal of the Site MP transport simulation is to evaluate the remediation alternative in term of ground-water restoration to the MCLs within the site boundary. The simulations were run for 10 years. Figures A-6 through A-13 show simulated PCE, TCE, DCE, and VC contours for each remediation alternative at first and fifth year. At year ten, all remediation alternatives obtain MCLs within the site boundary except for VC in the no action alternative.

A visual inspection of concentration plots indicates that overall achievement was obtained regarding area of cleanup within the site boundary for the existing pumping alternative. No significant accelerating was made for the two more intensive cleanup alternatives.

In conclusion, there is no need for a continuing PCE source term for 35 years with high concentration level for Zone 4 off-base transport simulation since residual concentrations from Site MP can be effectively reduced to their MCLs in a short time period.

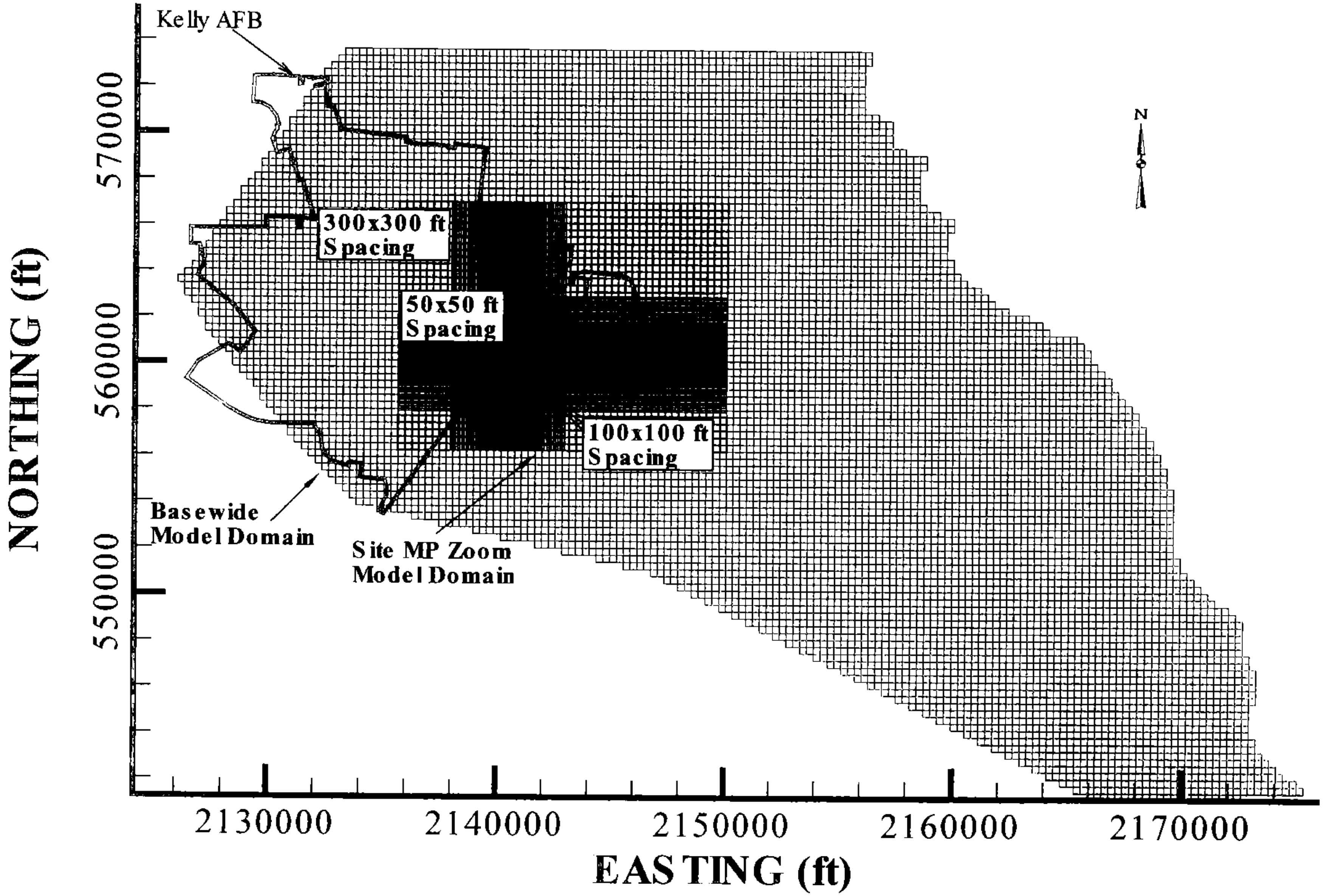


Figure A-1 Numerical Grid of Site MP Zoom Model Embedded within the Expanded Basewide Model

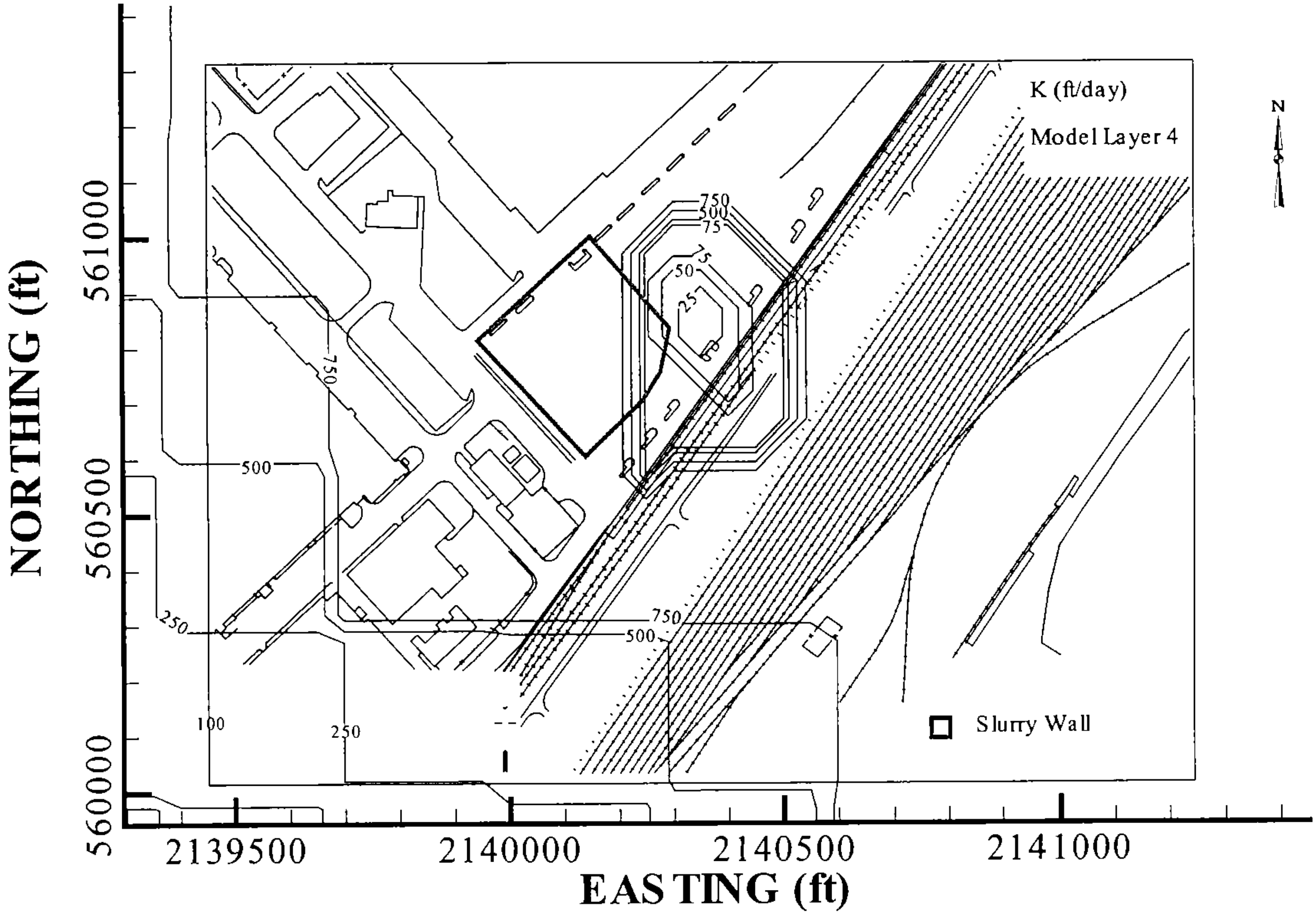


Figure A-2 Location of Slurry Wall and Contours of Hydraulic Conductivity (K) within Zoomed-In MP Model Domain

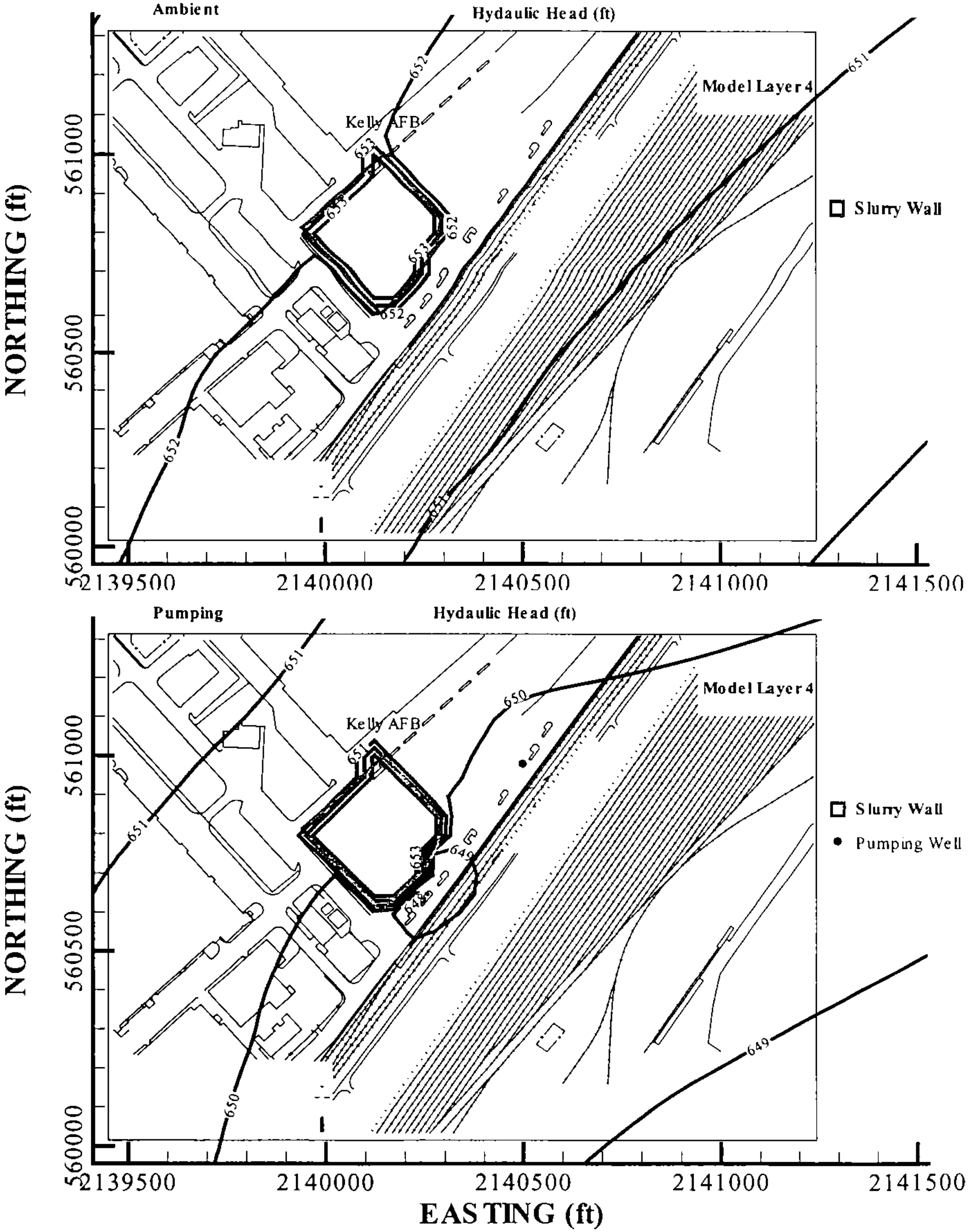
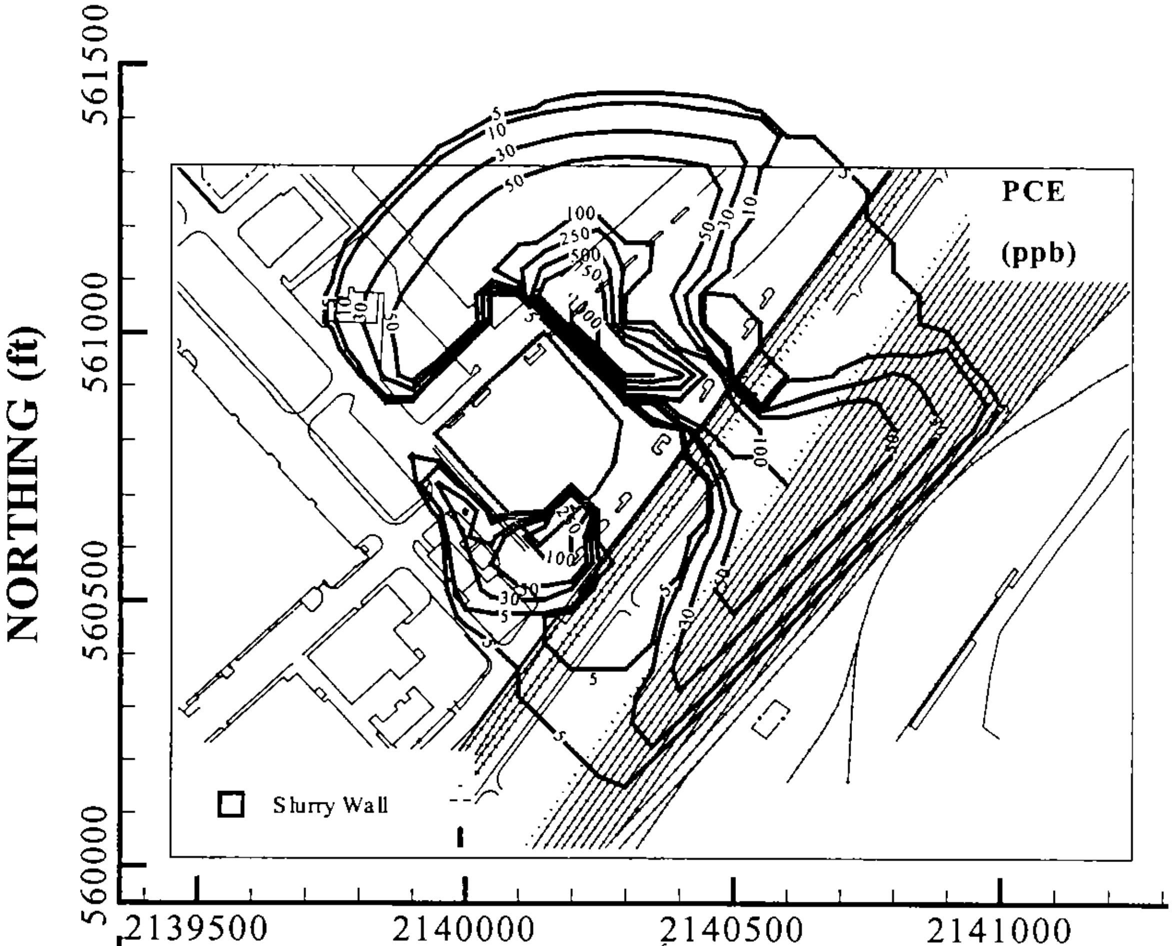


Figure A-3 Simulated Hydraulic Heads at Zoomed in Area for MP Zoom Model under Ambient and Pumping Conditions



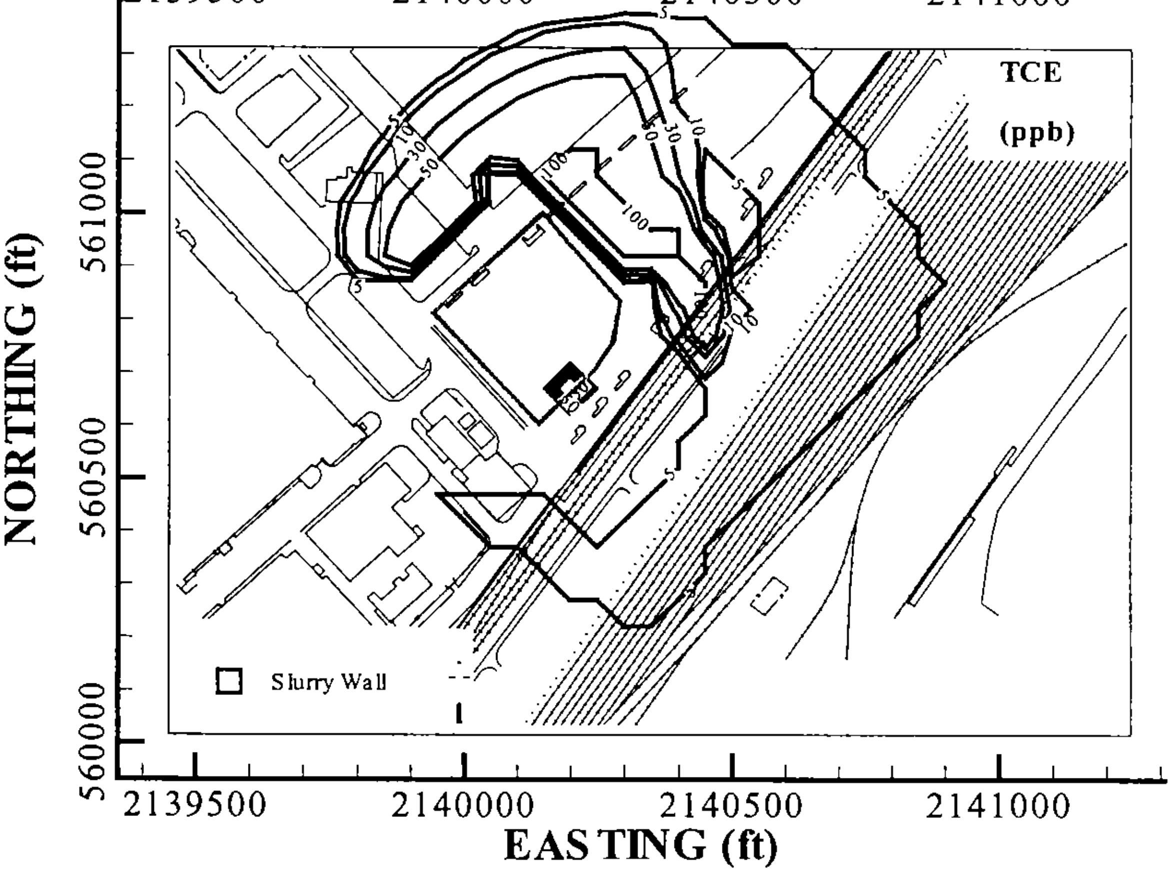


Figure A-4 PCE and TCE Concentration Contours for Transport Simulation of MP Zoom Model

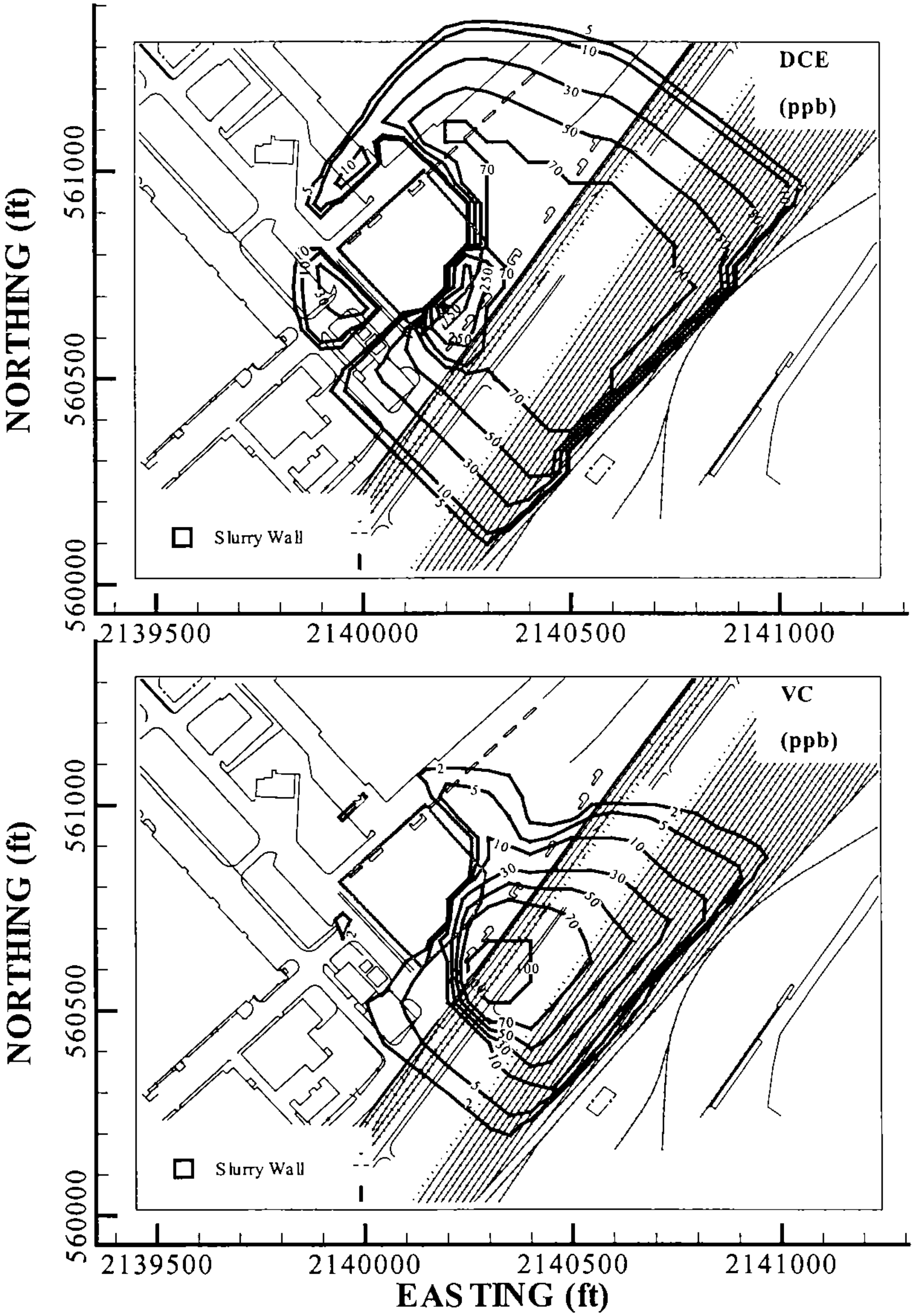


Figure A-5 DCE and VC Concentration Contours for Transport Simulation of MP Zoom Model

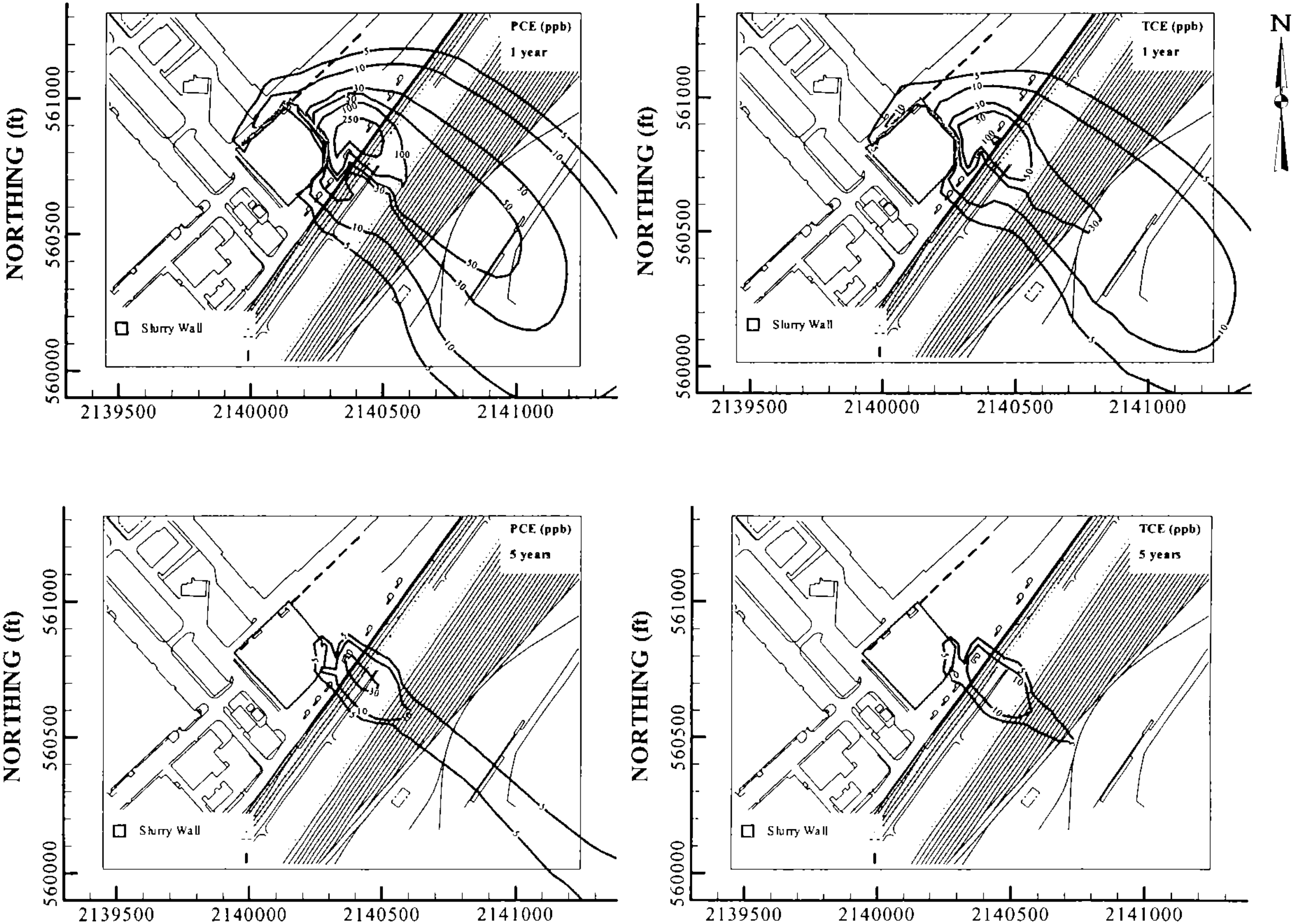


Figure A-6: Simulated PCE and TCE Contours for No Action Alternative

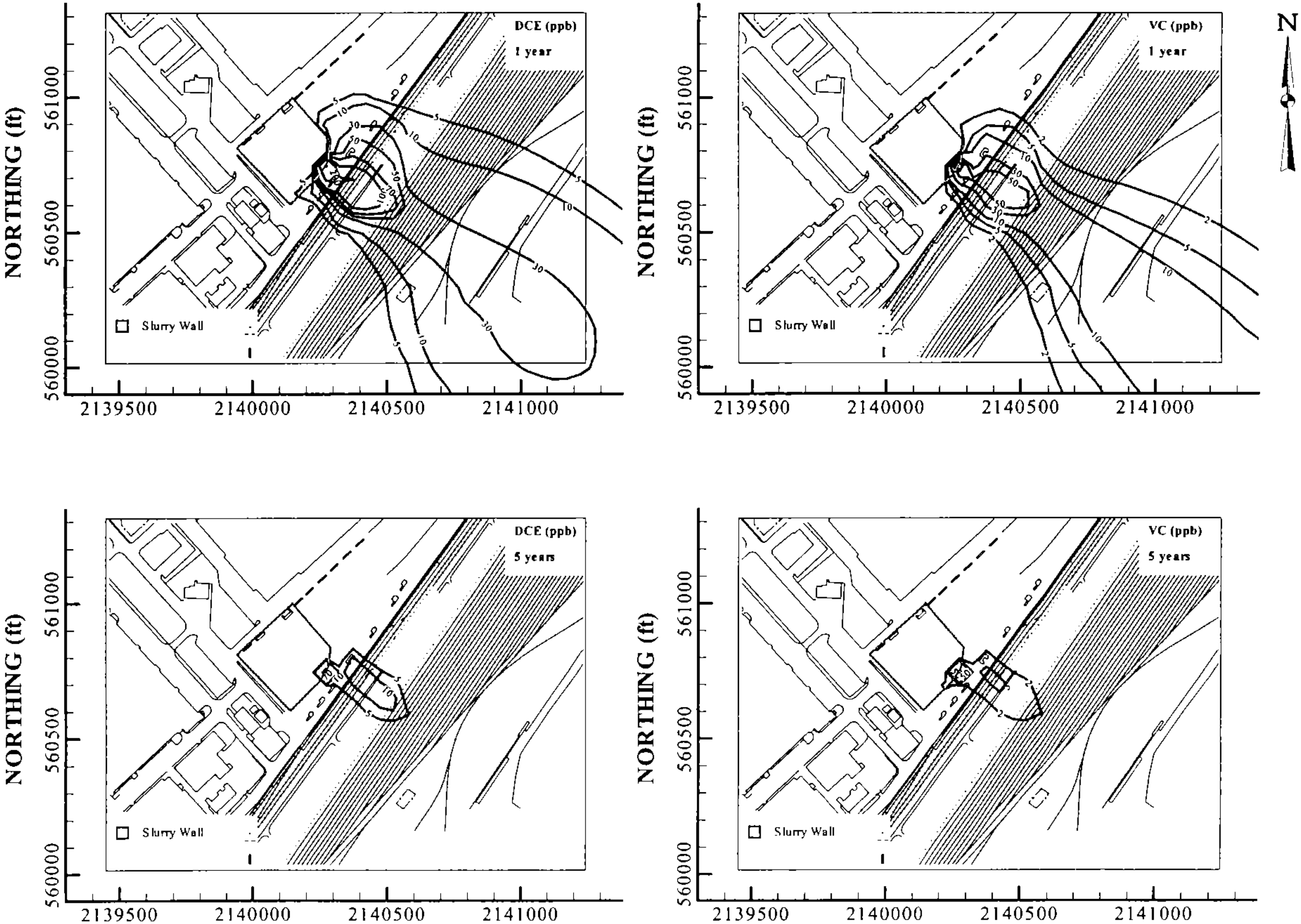


Figure A-7: Simulated DCE and VC Contours for No Action Alternative

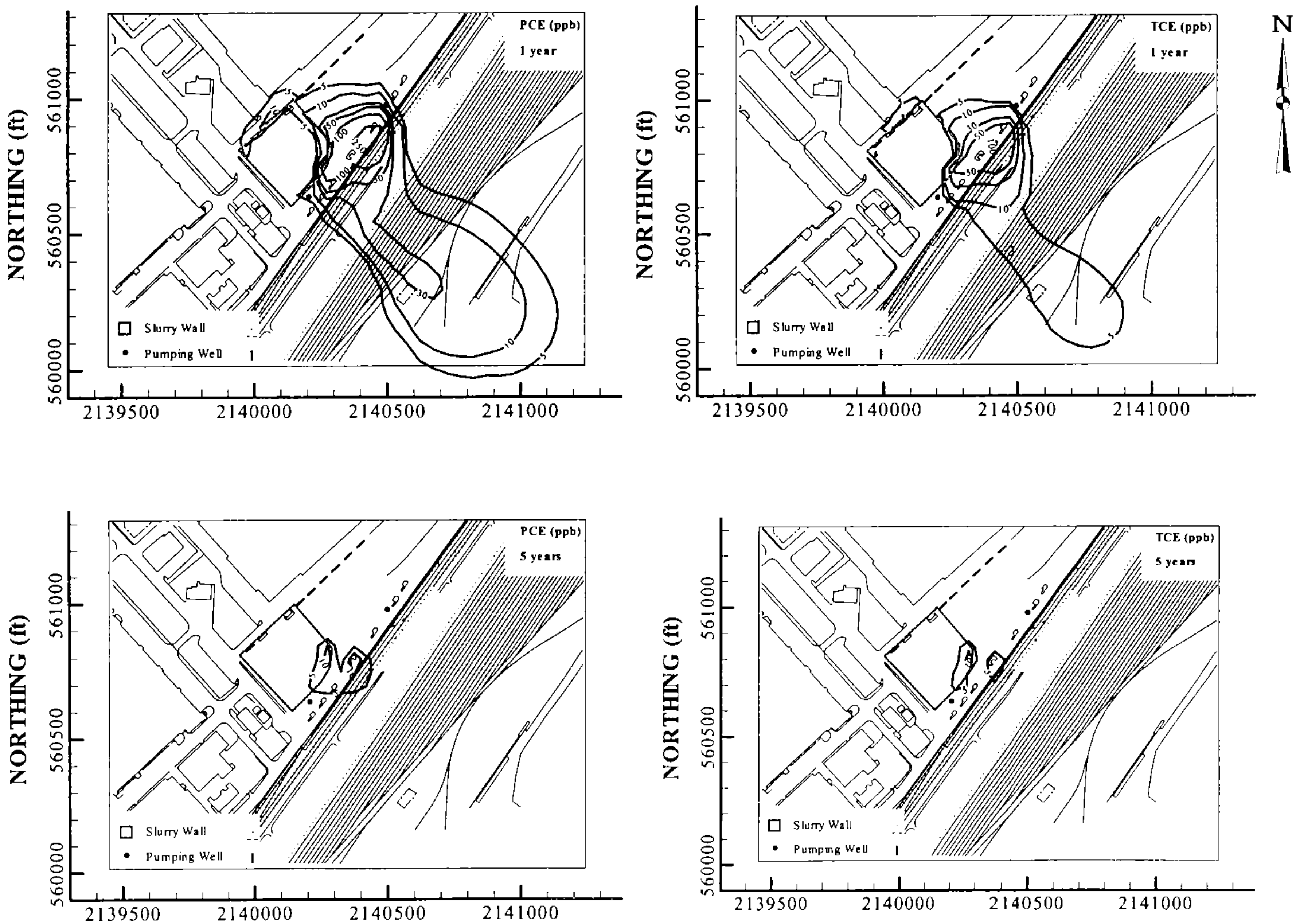


Figure A-8: Simulated PCE and TCE Contours for Existing Pumping Alternative

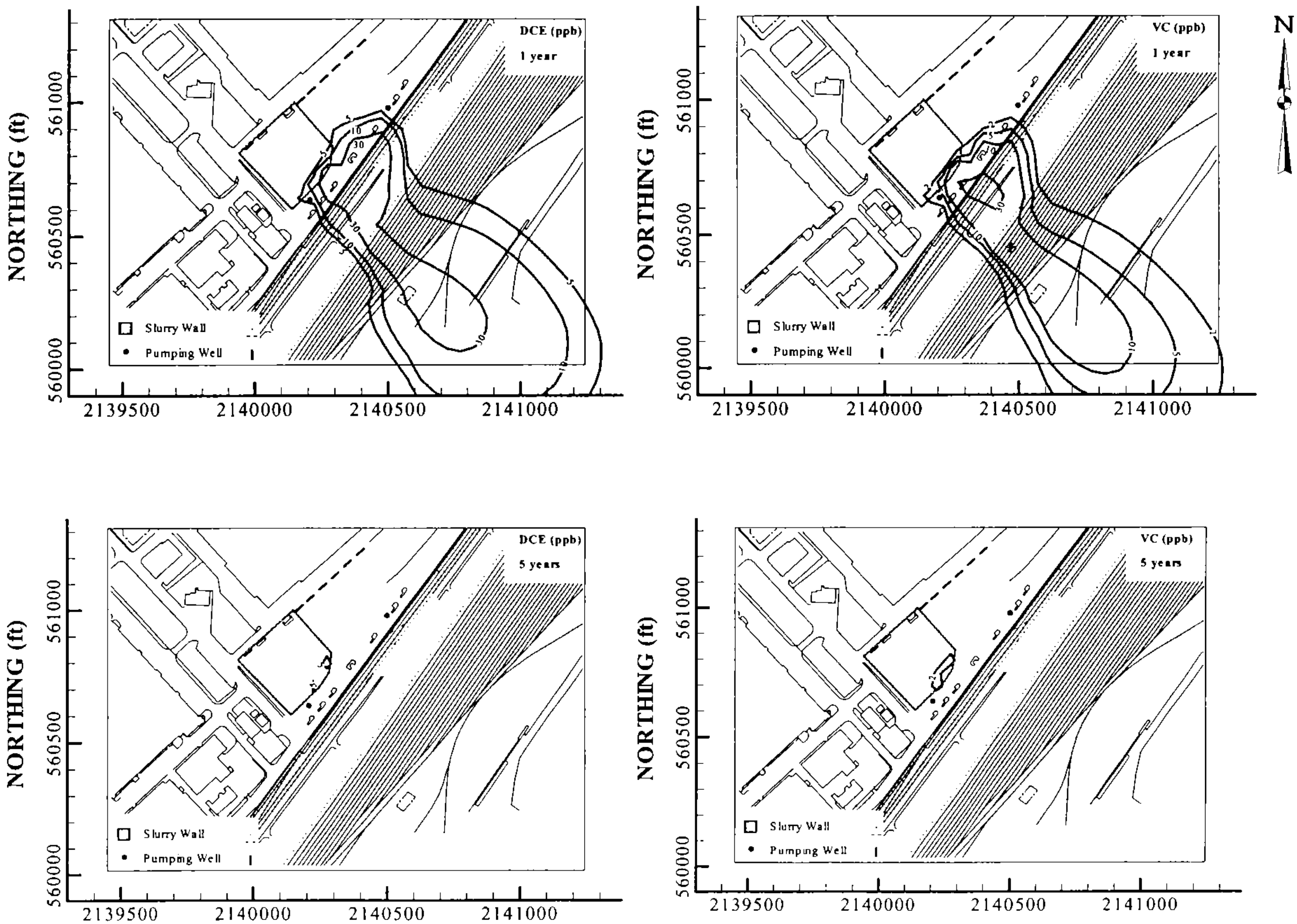


Figure A-9: Simulated DCE and VC Contours for Existing Pumping Alternative

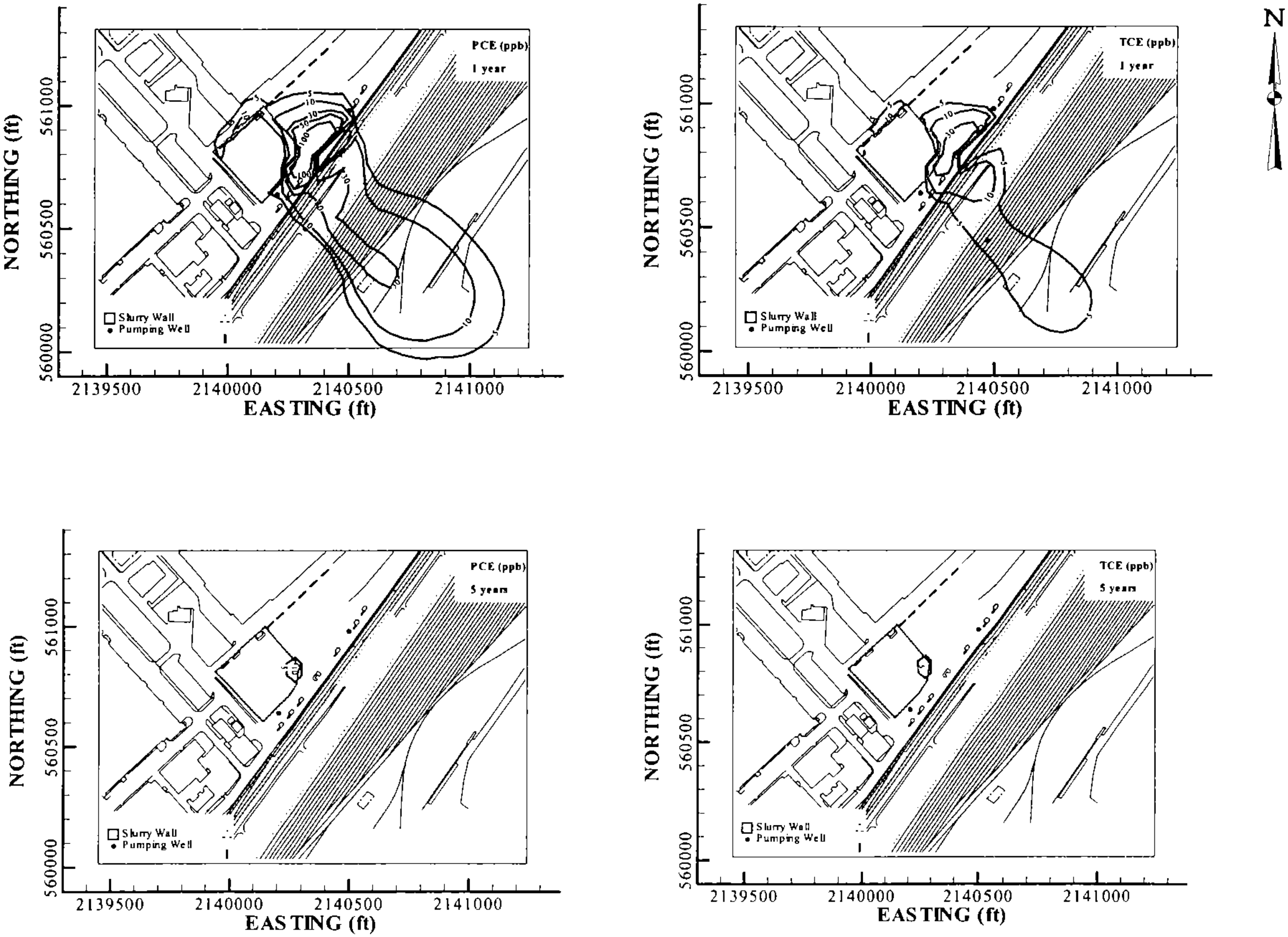


Figure A-10: Simulated PCE and TCE Contours for Enhanced Biotreatment Alternative

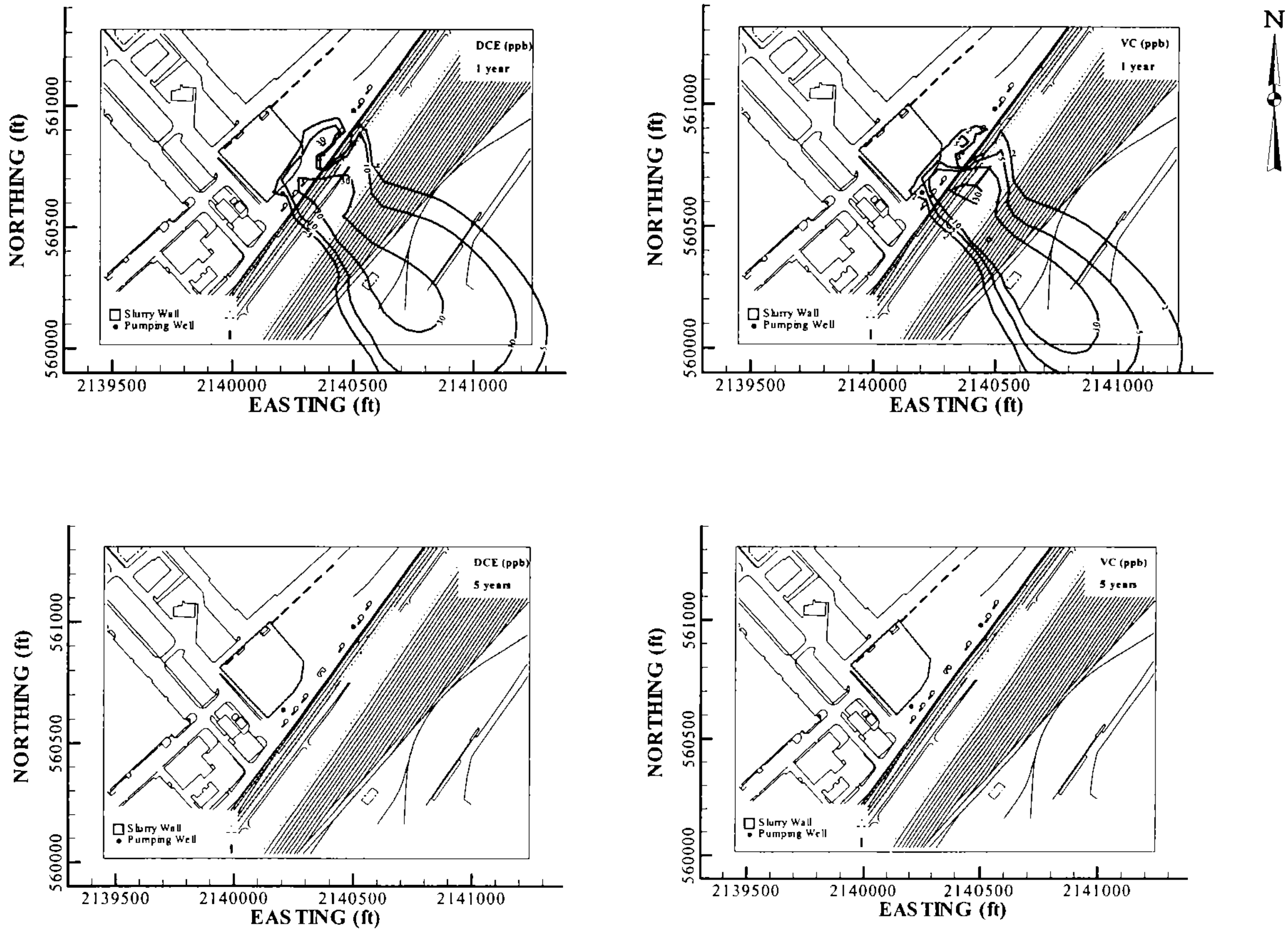


Figure A-11: Simulated DCE and VC Contours for Enhanced Biotreatment Alternative

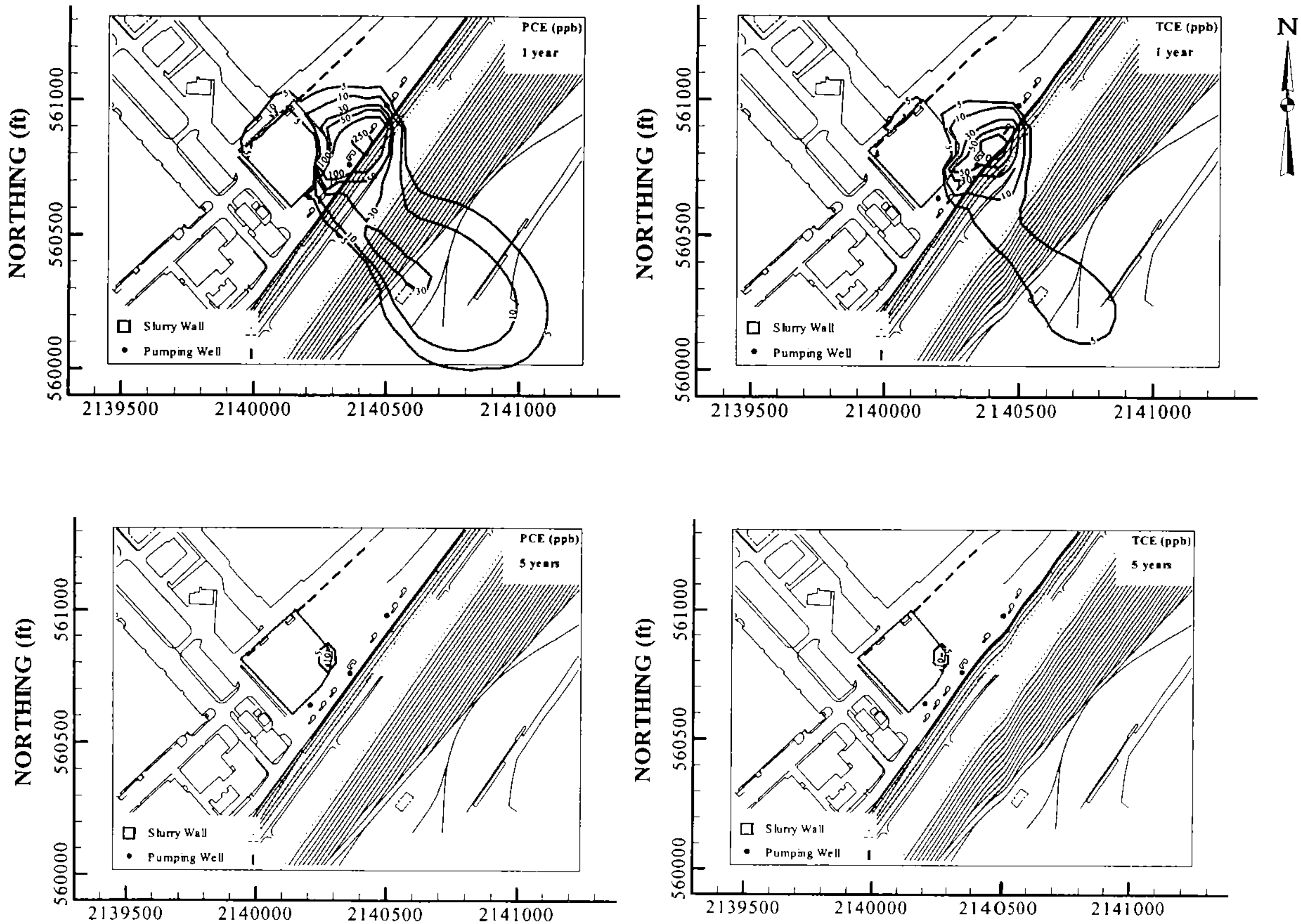


Figure A-12: Simulated PCE and TCE Contours for Existing System with Well RW134Alternative

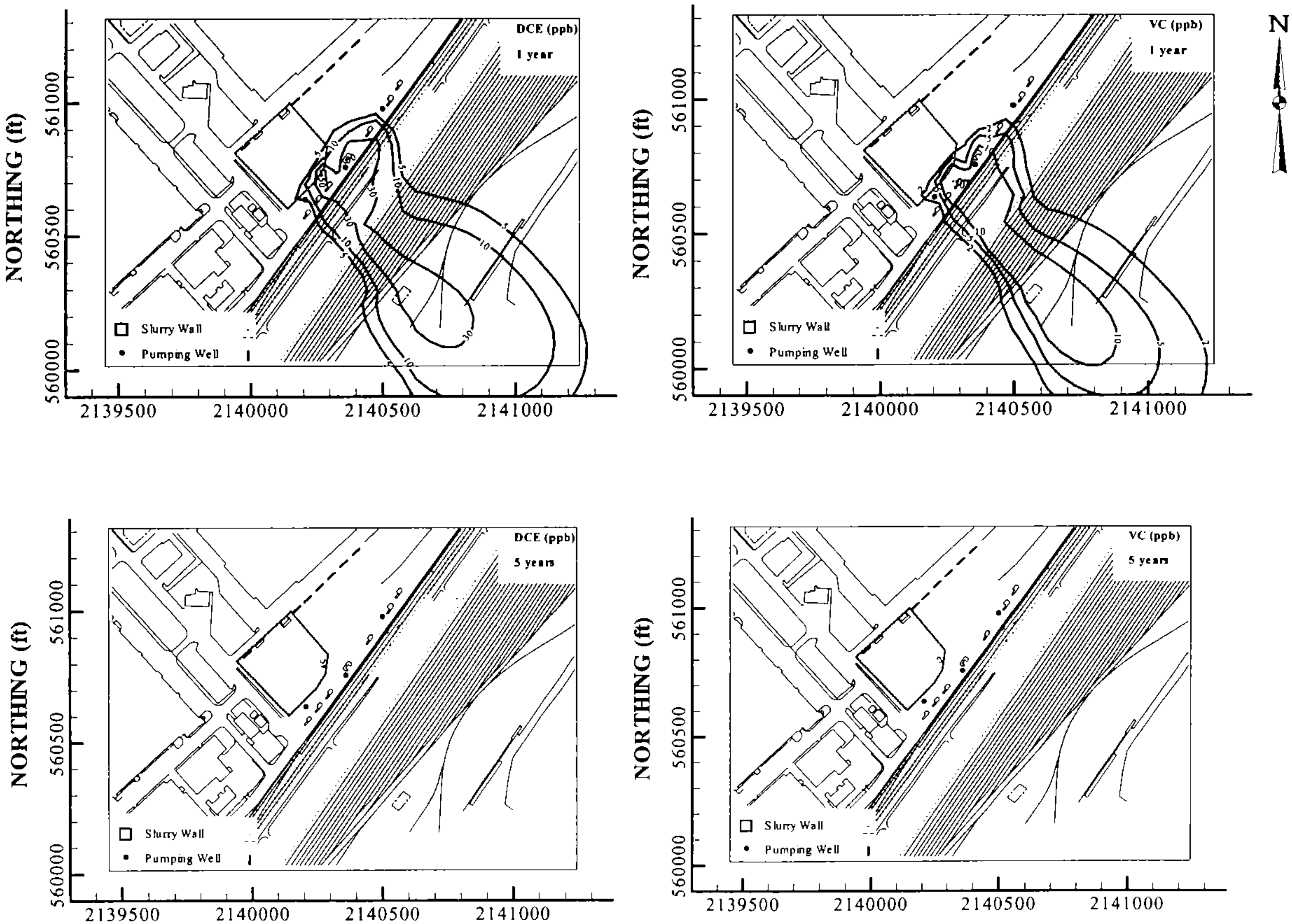


Figure A-13: Simulated DCE and VC Contours for Existing System with Well RW134 Alternative

APPENDIX A ADDENDUM

Modeling Results for the Preferred Alternative

GROUNDWATER FLOW AND TRANSPORT SIMULATION FOR THE PREFERRED REMEDIATION ALTERNATIVE

ADDENDUM TO

DEVELOPMENT OF A BASEWIDE GROUNDWATER FLOW MODEL AND ITS APPLICATION FOR SIMULATING ZONE 4 REMEDIATION OPTIONS AT KELLY AFB, TEXAS

DRAFT FINAL

Prepared for:

Air Force Center for Environmental Excellence
Brooks AFB, Texas

Project No. MBPB98-7903
Contract F41624-95-D-8005-0031
Delivery Order 031

Prepared by:
HydroGeoLogic, Inc.
12343 Hymeadow Drive, Suite 3B
Austin, Texas 78750

February 2002

Table of Contents

Section | Page

1.0 INTRODUCTION

As a continued effort to maintain a calibrated basewide groundwater flow model at Kelly Air Force Base (AFB), HydroGeoLogic, Inc. developed an expanded basewide flow model based on April 1999 data in FY2001. The April 1999 basewide mode was extracted and refined to generate a Zone 4 off-base zoom model. The Zone 4 zoom model was used to perform transport simulations for 12 remediation options as Phase 1, and 6 most feasible remediation options as Phase 2 to support the Zone 4 Corrective Action Study (CMS). Model development and simulation results were detailed in a Draft Final Report: Development of a Basewide Groundwater Flow Model and Its Application for Simulating Zone 4 Remediation Options at Kelly AFB, Texas.

A new preferred remediation alternative was simulated. In addition to the existing system control described as Option D in both Phase 1 and Phase 2 simulations, the preferred alternative consists of 3 vertical wells and 2 flow-through reactive walls. This addendum summarizes model simulation results for the preferred alternative.

2.0 FLOW FIELD

The same Zone 4 off-base groundwater flow model documented in the Section 4 of Draft Final report was used for the preferred alternative flow field simulation. Three new wells were placed to southeast of East Kelly in order to facilitate cleanup times. Table 2-1 provides locations and pumping rates for three new wells and the wells associated with Option D in the Draft Final report.

The model simulation was run until steady-state flow condition was achieved, and had a mass balance error less than 0.1%. Table 2-2 presents the water balance for the flow simulation.

Table 2-1: Locations and Pumping Rates for Preferred Alternative

Well Name	Easting (feet)	Northing (feet)	Model Row	Model Column	Flow gpm
New Wells					
RW_1	2144612	557590	165	84	10.90
RW_2	2146070	558111	160	113	14.29
RW_3	2146799	557381	166	128	9.98
Sub Total					35.16
East Kelly Horizontal and Vertical Wells (Proposed in Option D)					
HW-1	2143476	559165	145	61	72.00
HW-2	2143527	559174	145	62	25.00
HW-3	2145015	559009	148	91	11.50
HW-4	2145059	559021	148	92	30.00
HW-5	2146433	559530	138	120	35.00
HW-6	2146466	560270	123	121	30.00
HW-7	2146462	560402	121	121	30.00
HW-8	2146162	561909	97	116	30.00
HW-9	2146170	562212	91	115	50.00
HW-10	2145981	562683	75	111	50.00
VM_1	2142682	559455	140	45	35.00
VM_2	2142671	559265	144	45	25.00
VM_3	2142830	559248	144	48	25.00
Sub Total					448.50
Site MP (Proposed in Option D)					
RW56	2140207	560638	116	16	30.00
RW98	2140499	560979	109	17	35.00
Sub Total					65.00
Total					548.66

Table 2-2: Groundwater Fluxes (ft^3/day) Calculated by Flow Model

Mass	Recharge	River	Well	Drain	Model Boundary	Total Flux
In	461970	221040	0	0	674730	1357740
Out	-47257	-731570	-105544	-566	-474074	-1359011
Net	414713	-510530	-105544	-566	200656	-1271
Balance Error						-0.09%

3.0 TRANSPORT SIMULATION

The Zone 4 off-base flow and transport model was used to simulate fate and transport of PCE, TCE, DCE and VC for the preferred alternative. Two columns of flow-through reactive walls were placed in model cells associated with plume "hot spot" areas. The same transport parameters such as source terms and degradation rates for flow-through reactive walls used for previous Phase 2 simulations were input for transport run. Simulation results were also present in same formats as those in Phase 2.

The transport simulation was run for 25 years. Results are summarized using plots of concentration distributions at 5-year intervals starting at 0 years and ending at 25 years (Figures 3-1 through 3-3). At 25 years, plume concentration levels of PCE, TCE, DCE and VC are all below its individual MCLs. The concentration plots show the area enclosed by the MCL levels of 5 ppb, 5 ppb and 2 ppb for PCE, TCE and VC, respectively. Concentration plots of DCE are not shown because model results indicate that the DCE concentration is below its MCL at all time intervals.

Table 3-1 summarizes the area with contaminant concentrations above MCLs as a percentage of the existing plume at initial conditions for each compound. In the table, calculation for the contaminant area is presented for the plume at both East Kelly and off base. Table 3-2 summarizes the time (years) at which the maximum concentration has dropped below its MCLs.

Compared to simulation results of existing system control of Option D, cleanup times and area reduction within East Kelly are similar. For off-base portion of plume, improvement was made particularly to TCE and VC. At years 5 and 10, contaminated areas were reduced significantly. In terms of cleanup time to reach MCLs, VC was reduced from 20 years to 15 years.

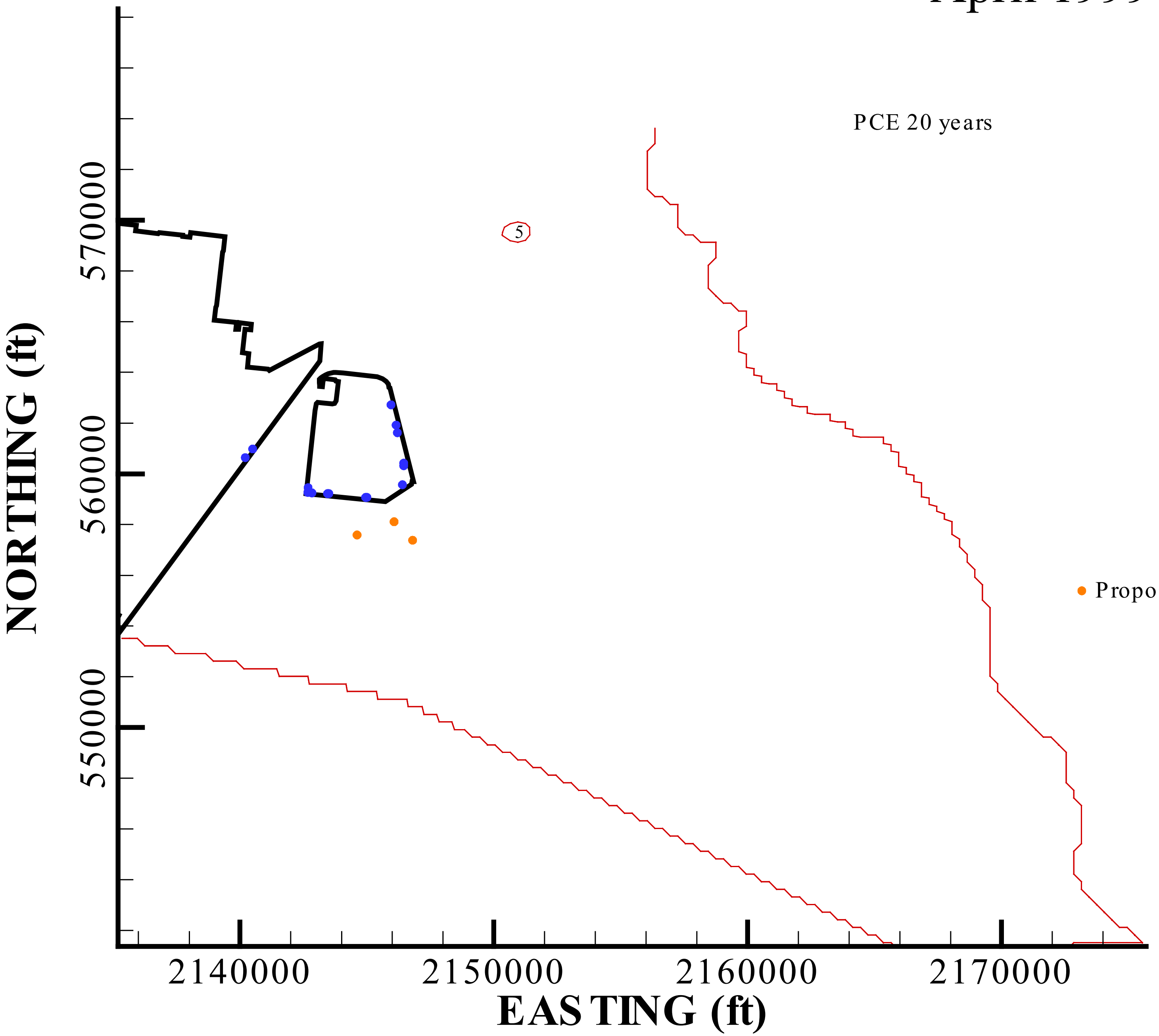
Table 3-1: Area Remaining Contaminated in Acre and Percentage (Preferred Remediation Alternative)

Years	Acre	Percent	Acre	Percent
PCE	Off Base		East Kelly	
0	4158		179	
5	1374	33.1%	5	2.7%
10	230	5.5%	0	0.0%
15	51	1.2%	0	0.0%
20	14	0.3%	0	0.0%
25	0	0.0%	0	0.0%
TCE	Off Base		East Kelly	
0	3897		318	
5	1374	35.3%	147	46.1%
10	230	5.9%	37	11.6%
15	51	1.3%	0	0.0%
20	14	0.4%	0	0.0%
25	0	0.0%	0	0.0%
VC	Off Base		East Kelly	
0	32		6	
5	360	1124.6%	0	0.0%
10	227	709.0%	0	0.0%
15	0	0.0%	0	0.0%
20	0	0.0%	0	0.0%
25	0	0.0%	0	0.0%

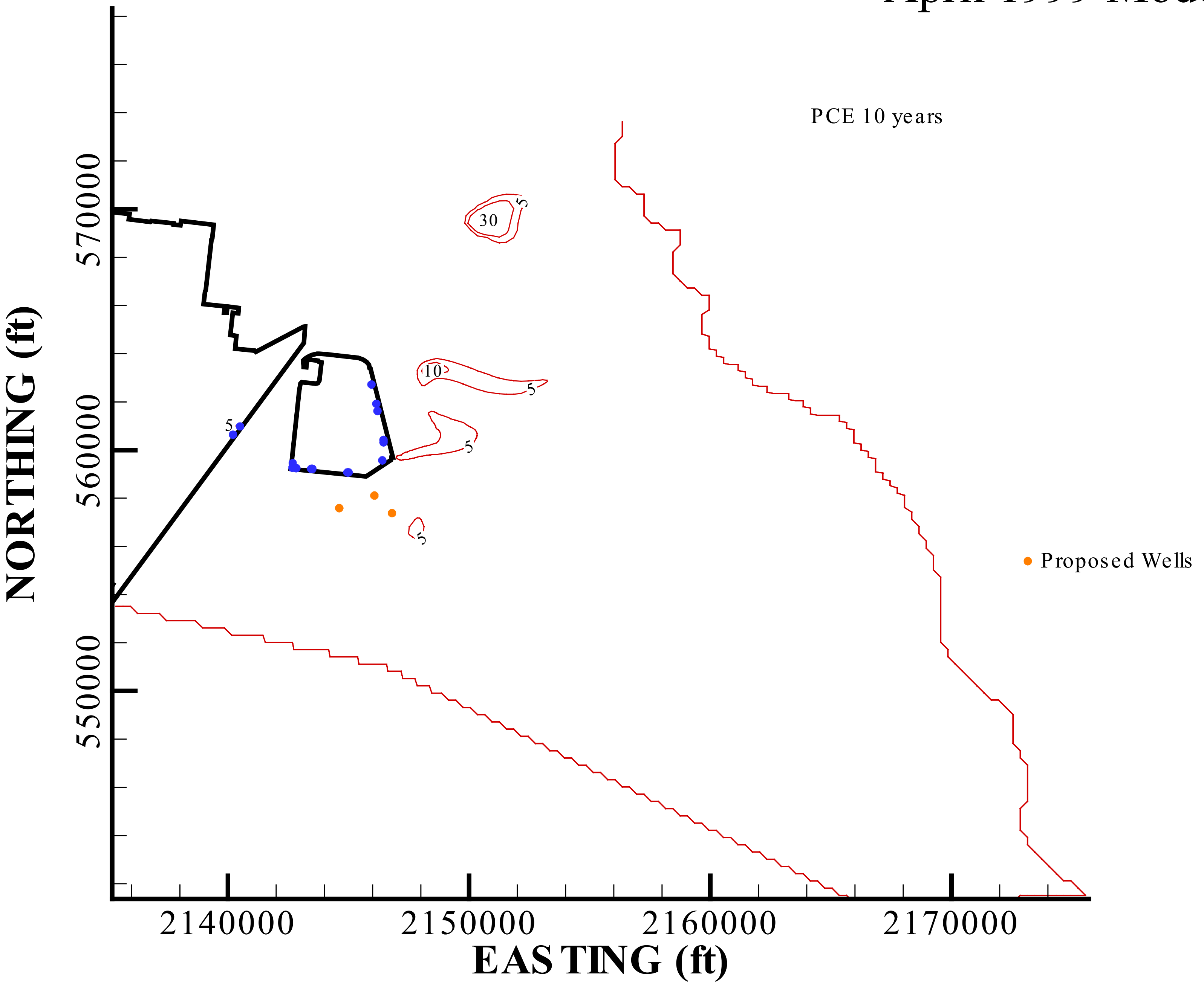
Table 3-2: Time (years) for the Maximum Concentration to Reach the MCLs

PCE		TCE		VC	
East Kelly	Off-Base	East Kelly	Off-Base	East Kelly	Off-Base
10	25	15	25	5	15

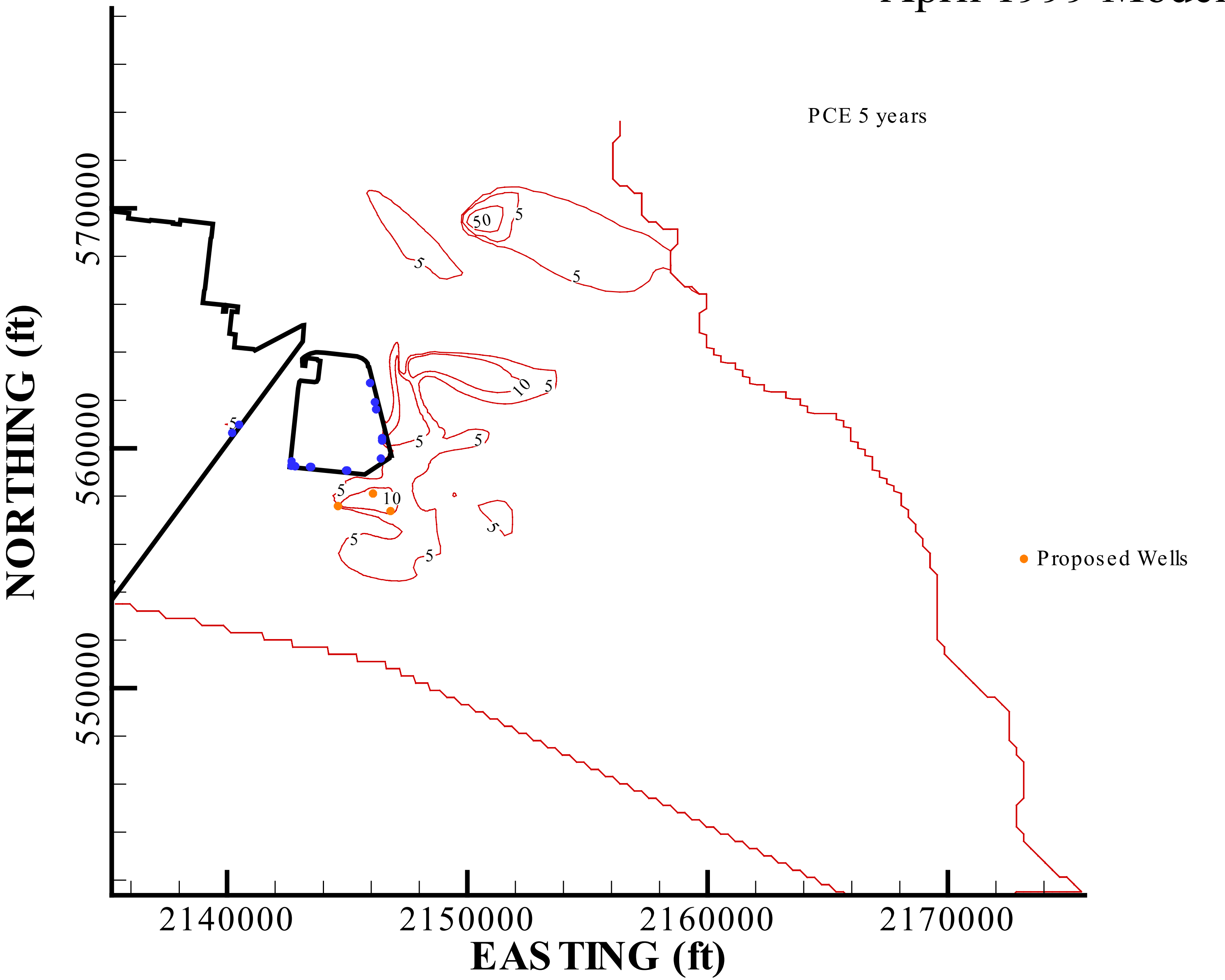
April 1999 Model



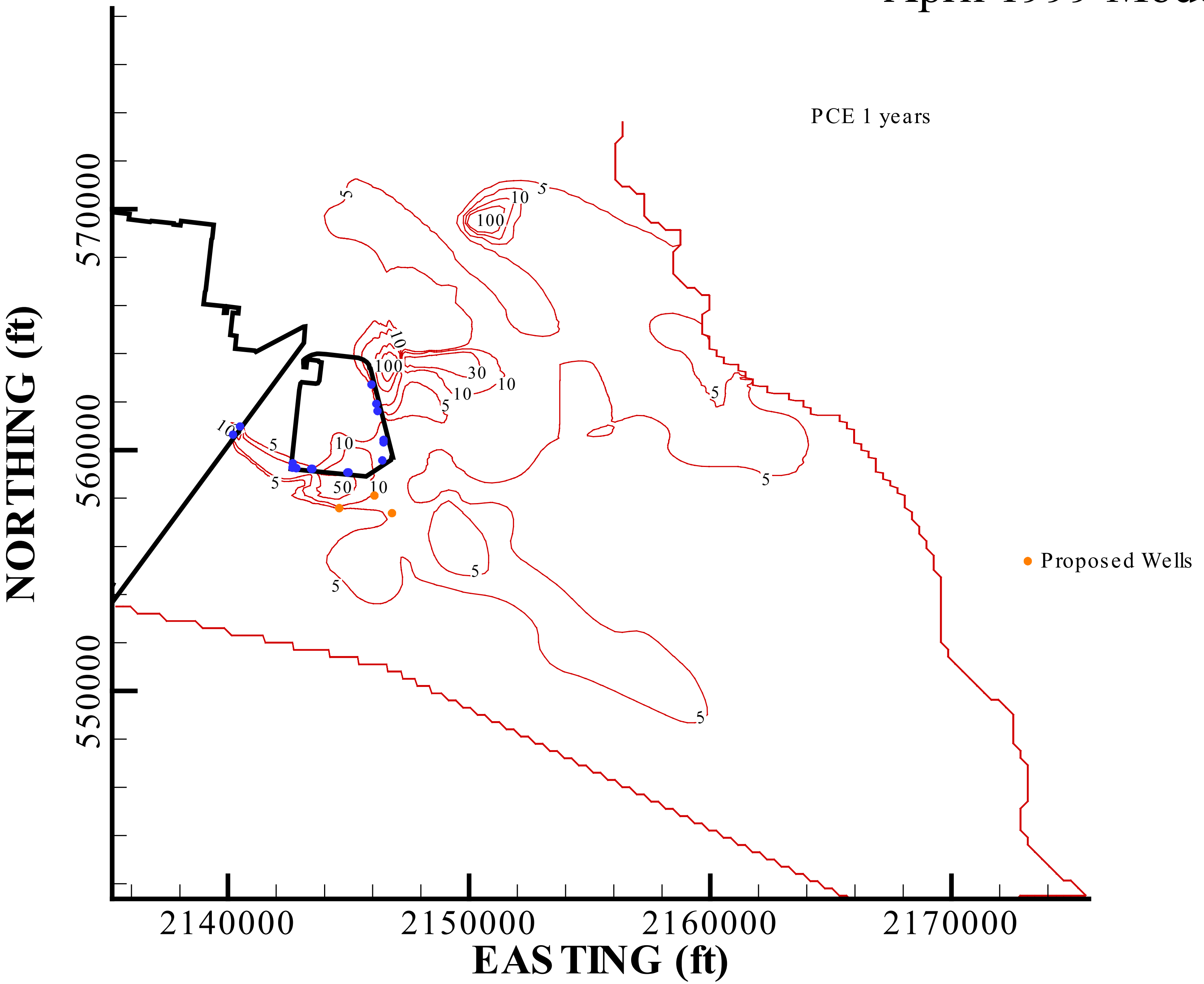
April 1999 Model



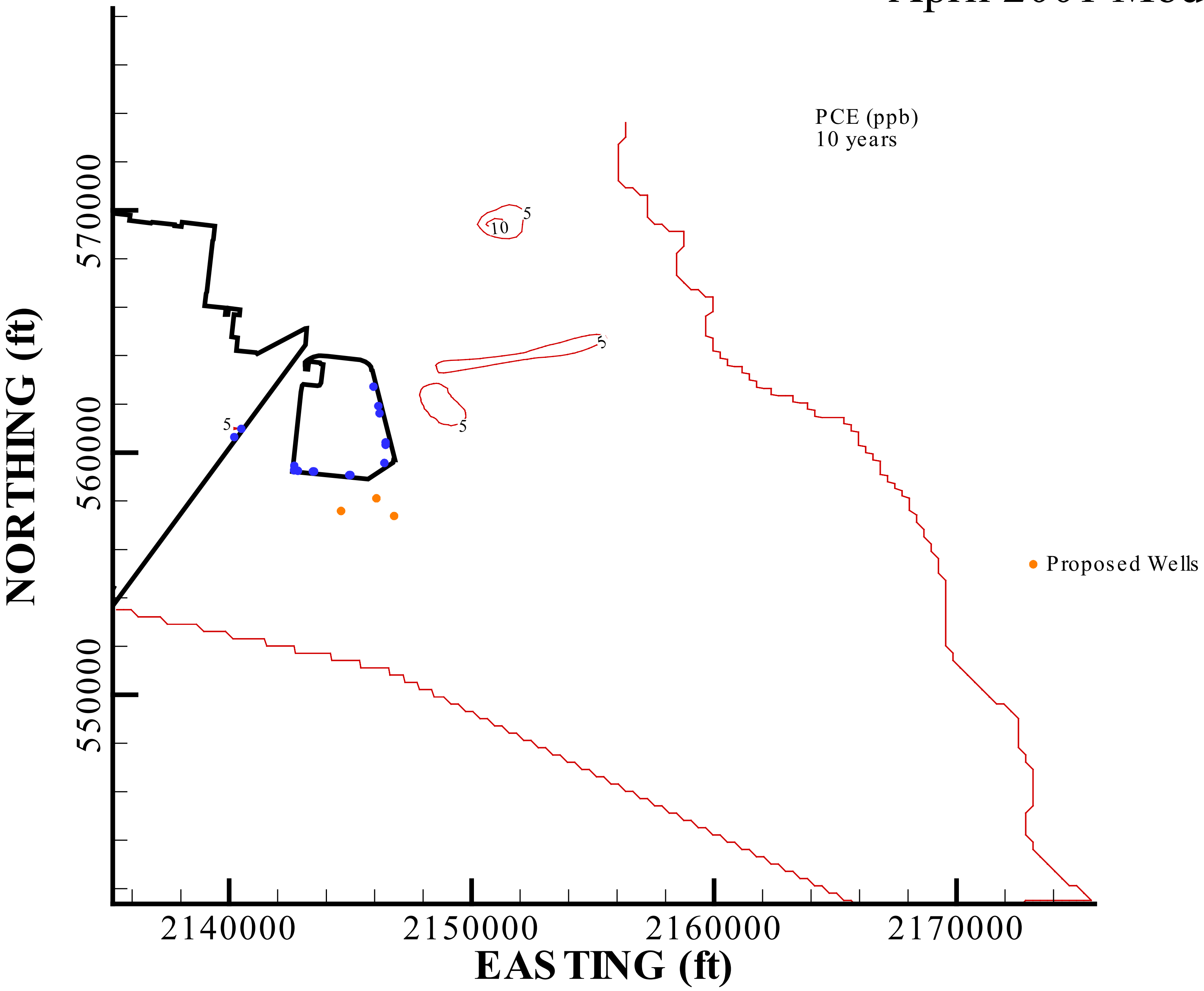
April 1999 Model

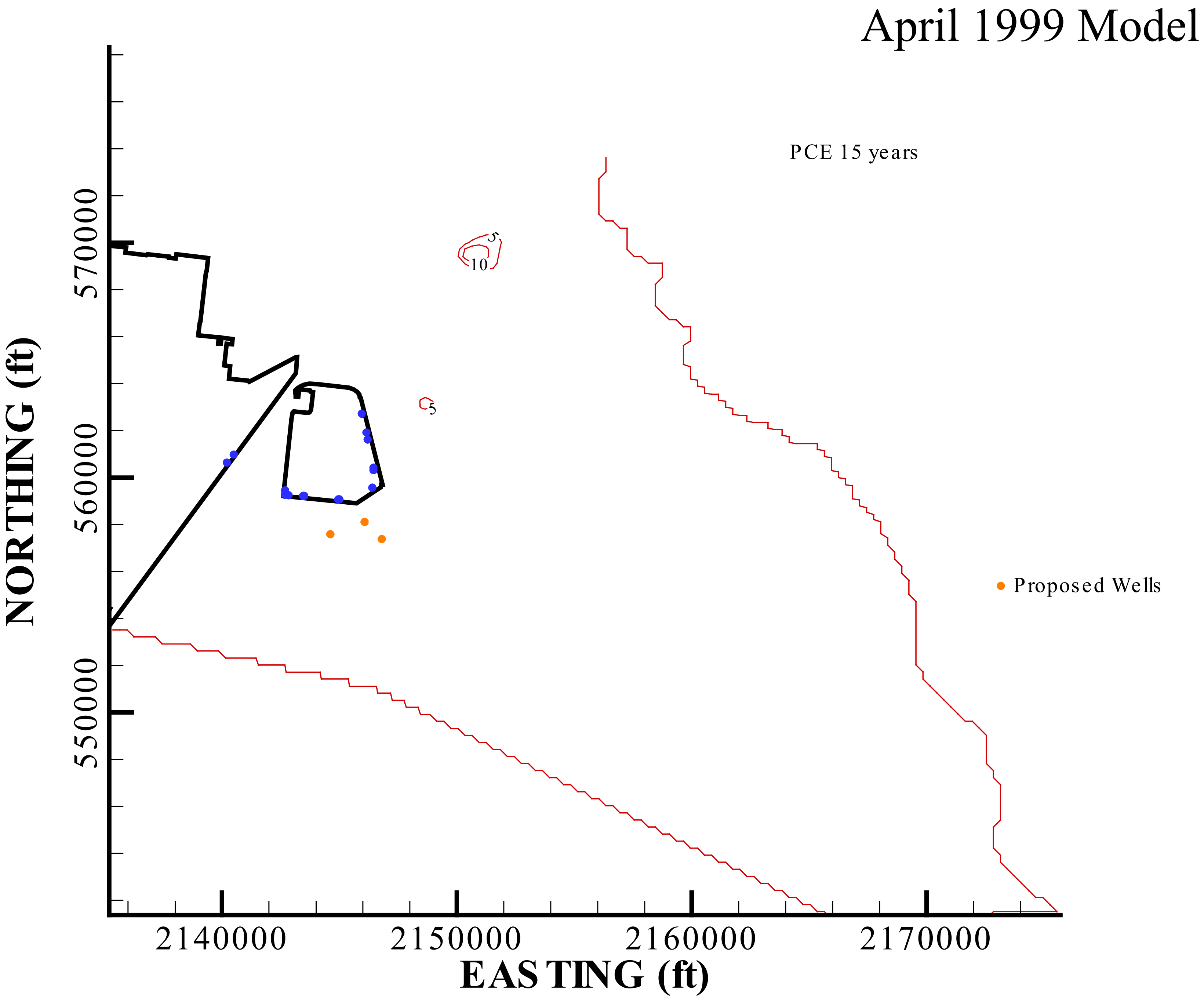


April 1999 Model



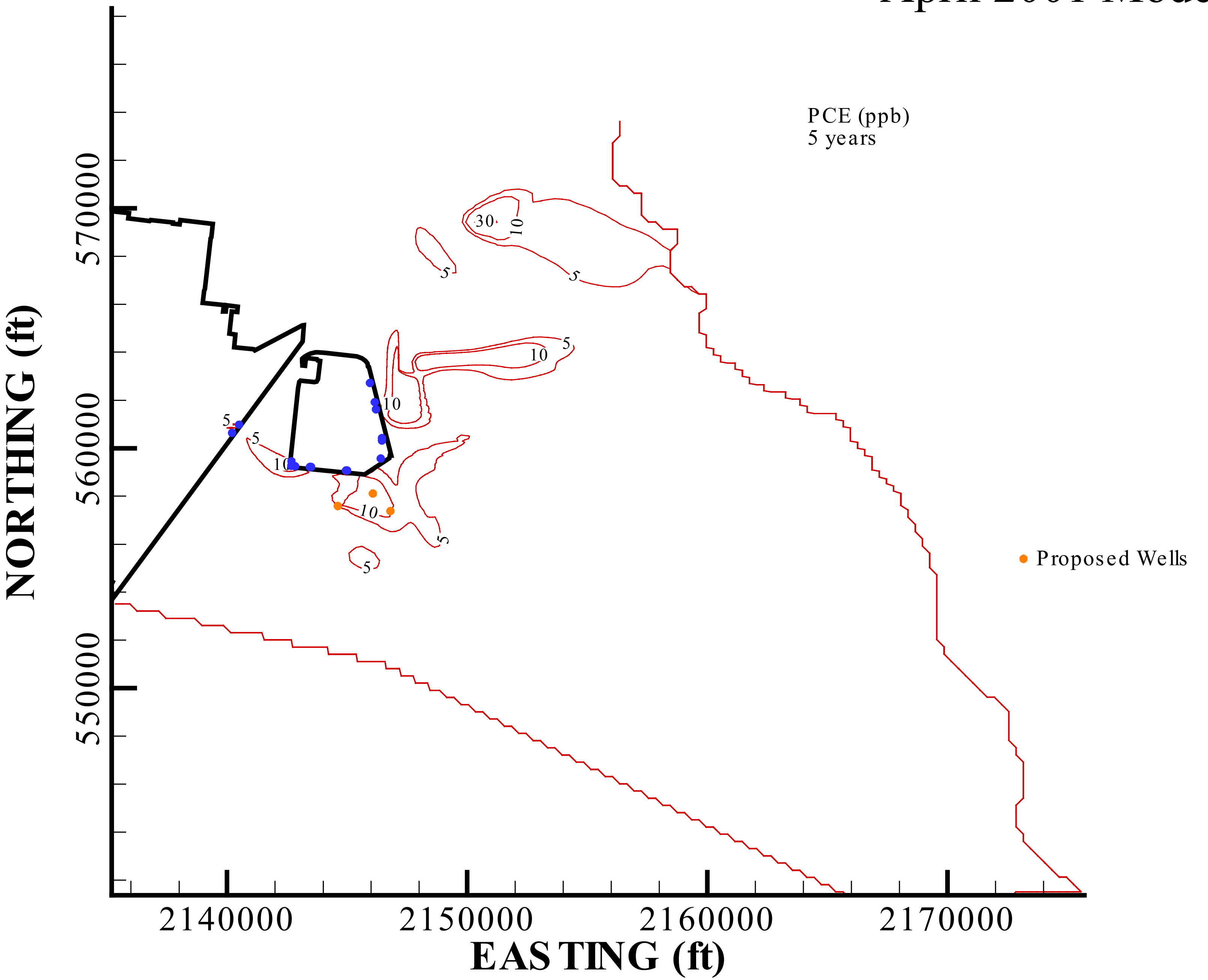
April 2001 Model

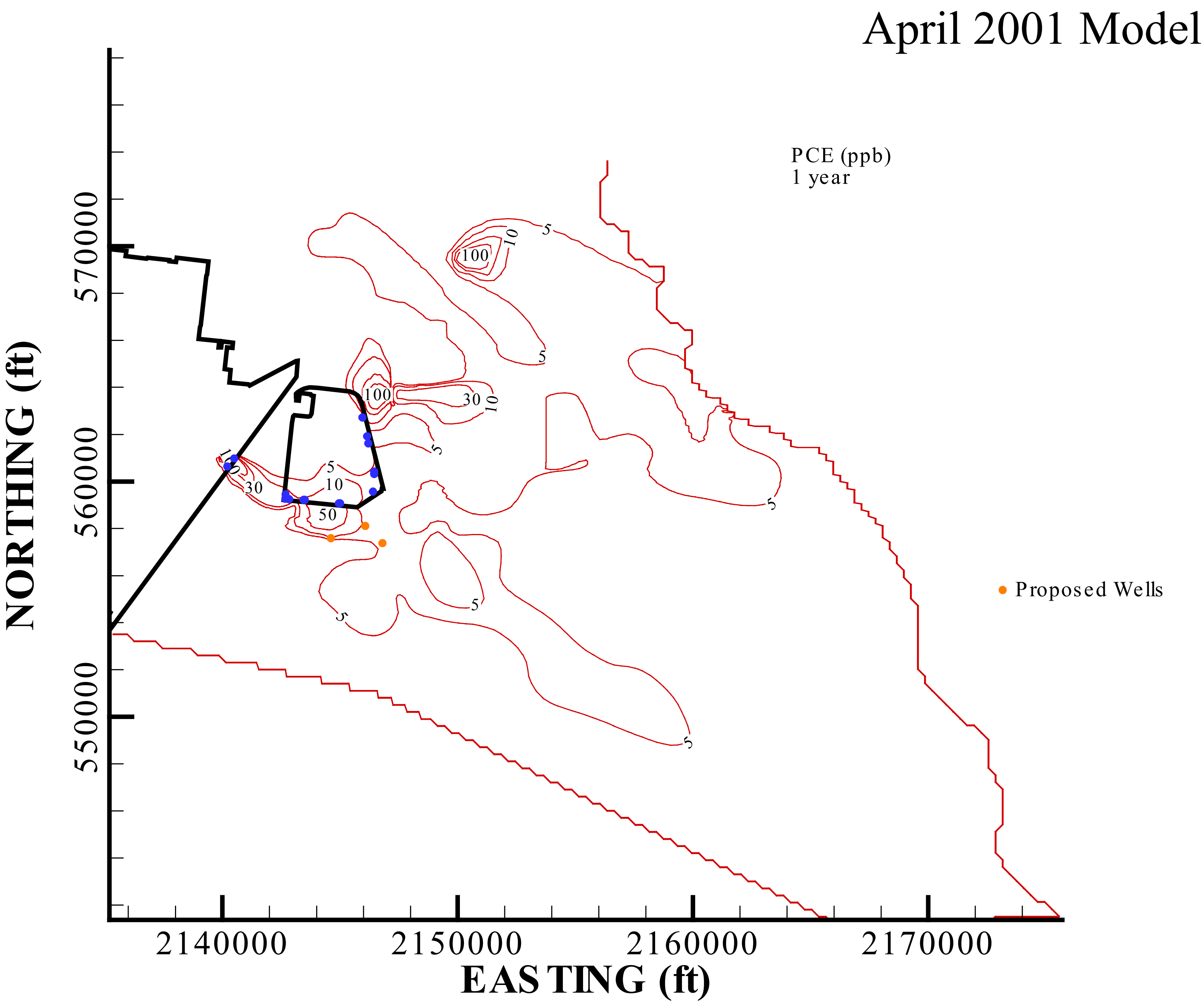




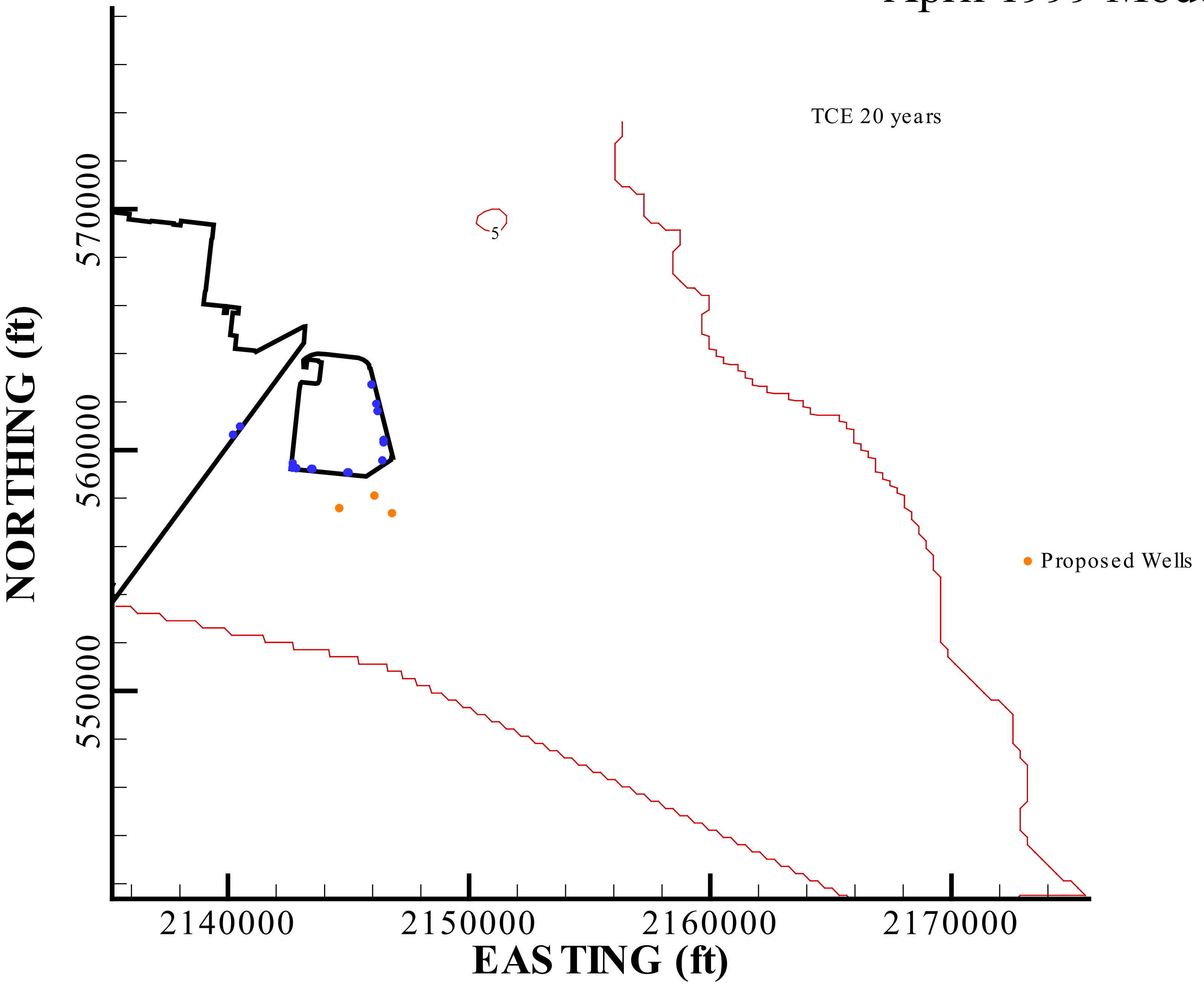
April 1999 Model
PCE 15 years
5
10
5
Proposed Wells
NORTHING (ft)
5700000
5600000
5500000
EASTING (ft)
2140000
2150000
2160000
2170000

April 2001 Model

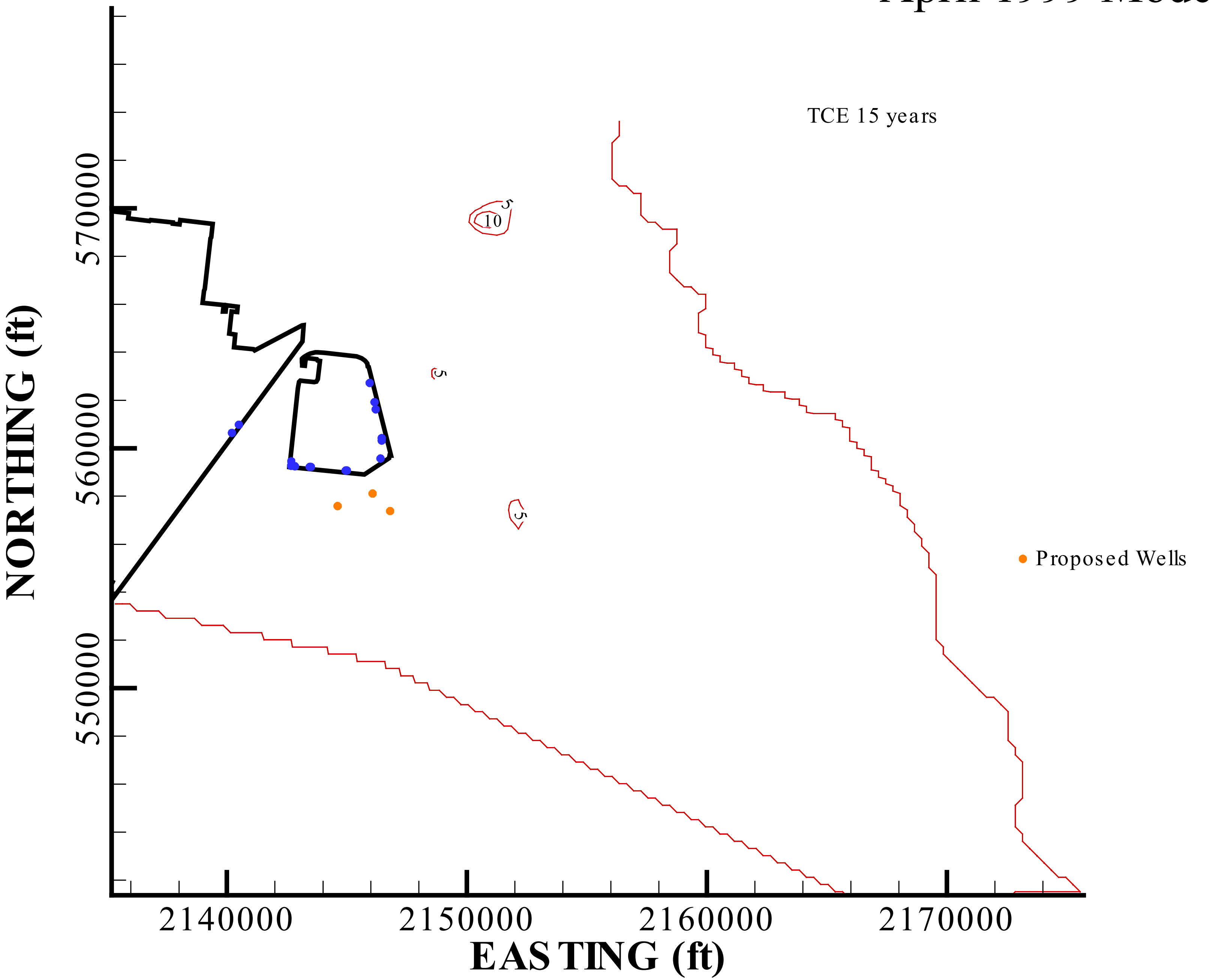



April 2001 Model
PCE (ppb)
1 year
Proposed Wells
NORTHING (ft)
EASTING (ft)
5700000
5600000
5500000
2140000
2150000
2160000
2170000
100
10
5
30
50

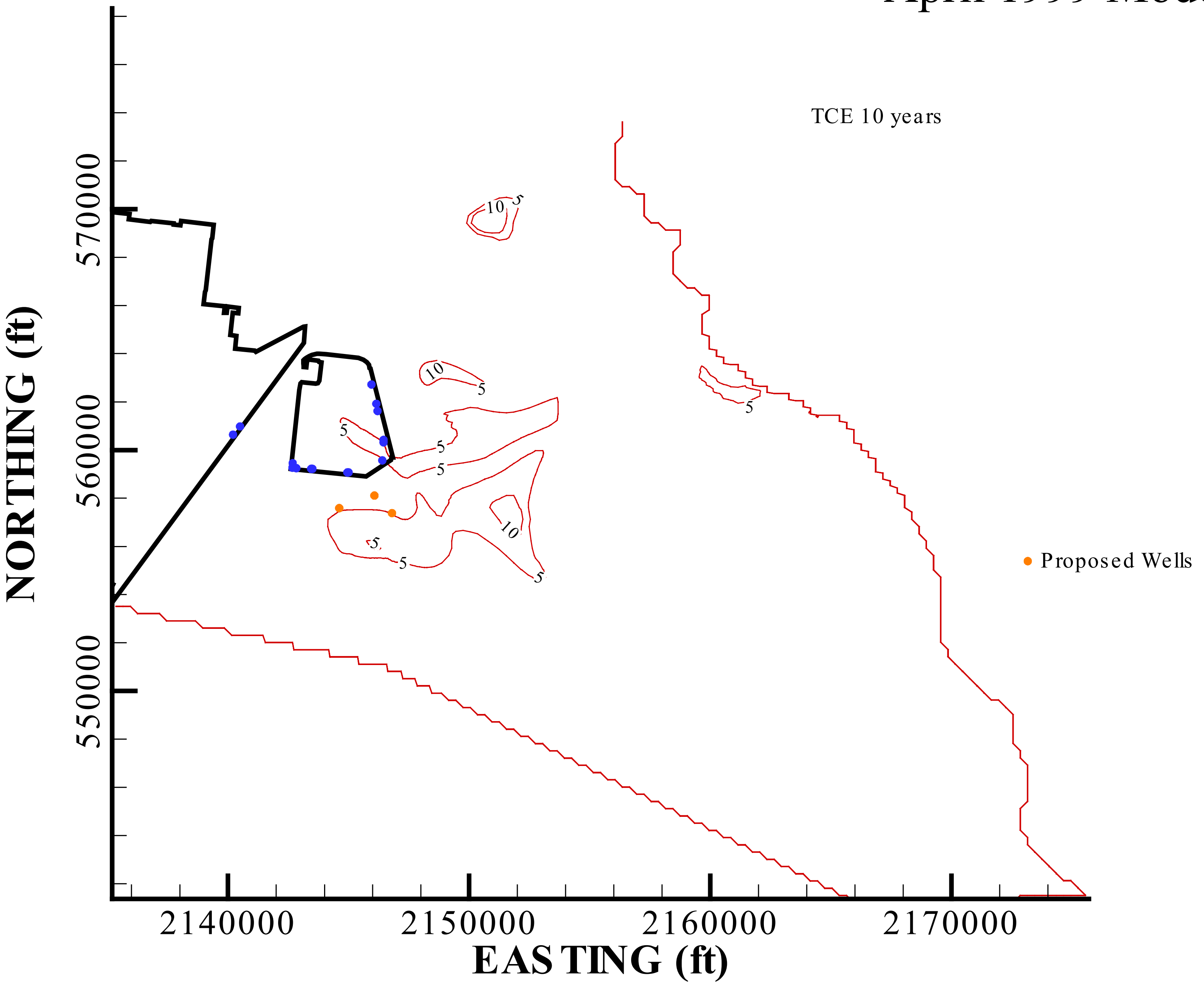
April 1999 Model

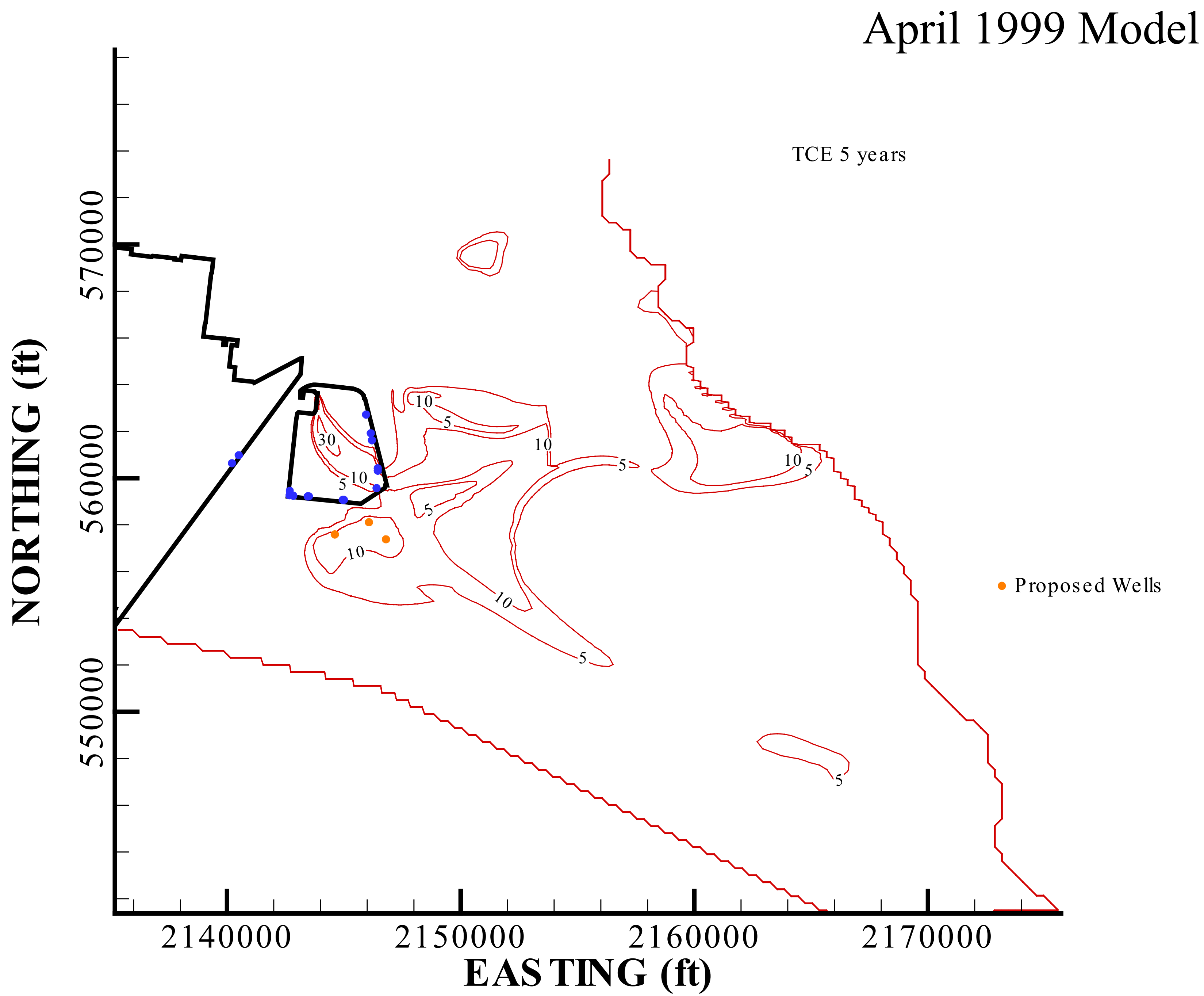


April 1999 Model

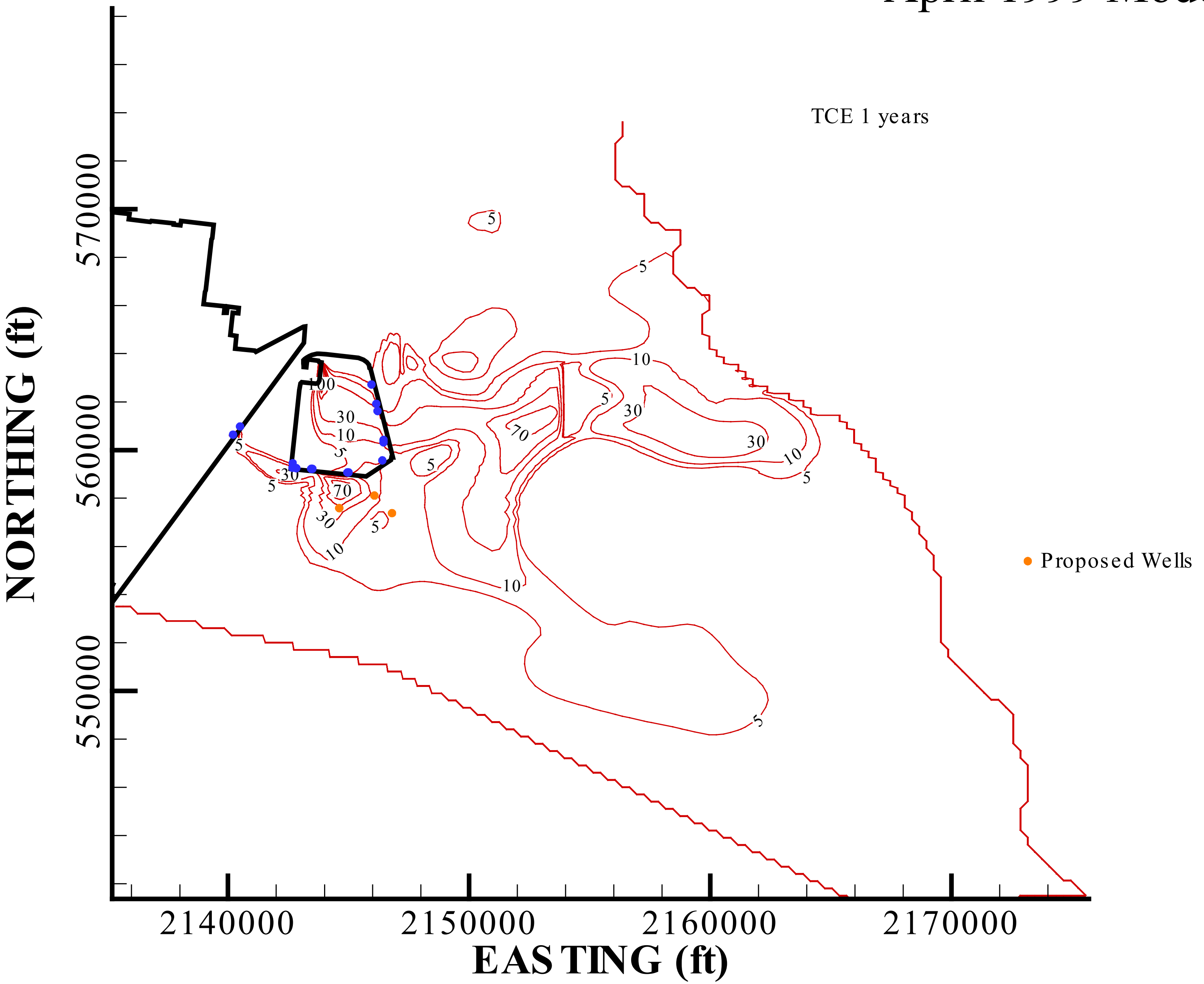


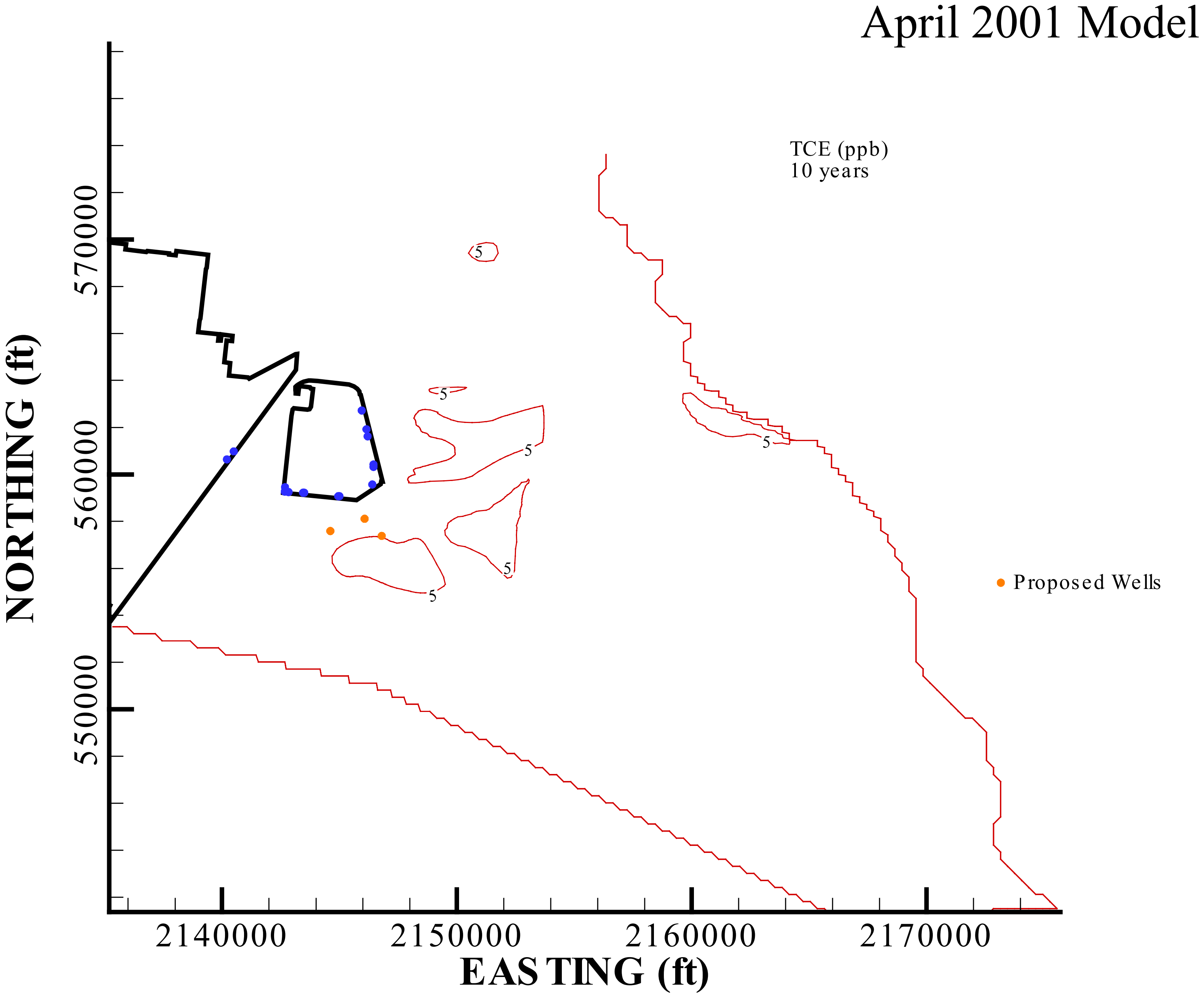
April 1999 Model




April 1999 Model
TCE 5 years
Proposed Wells
NORTHING (ft)
EASTING (ft)
5700000
5600000
5500000
2140000
2150000
2160000
2170000
30
10
5

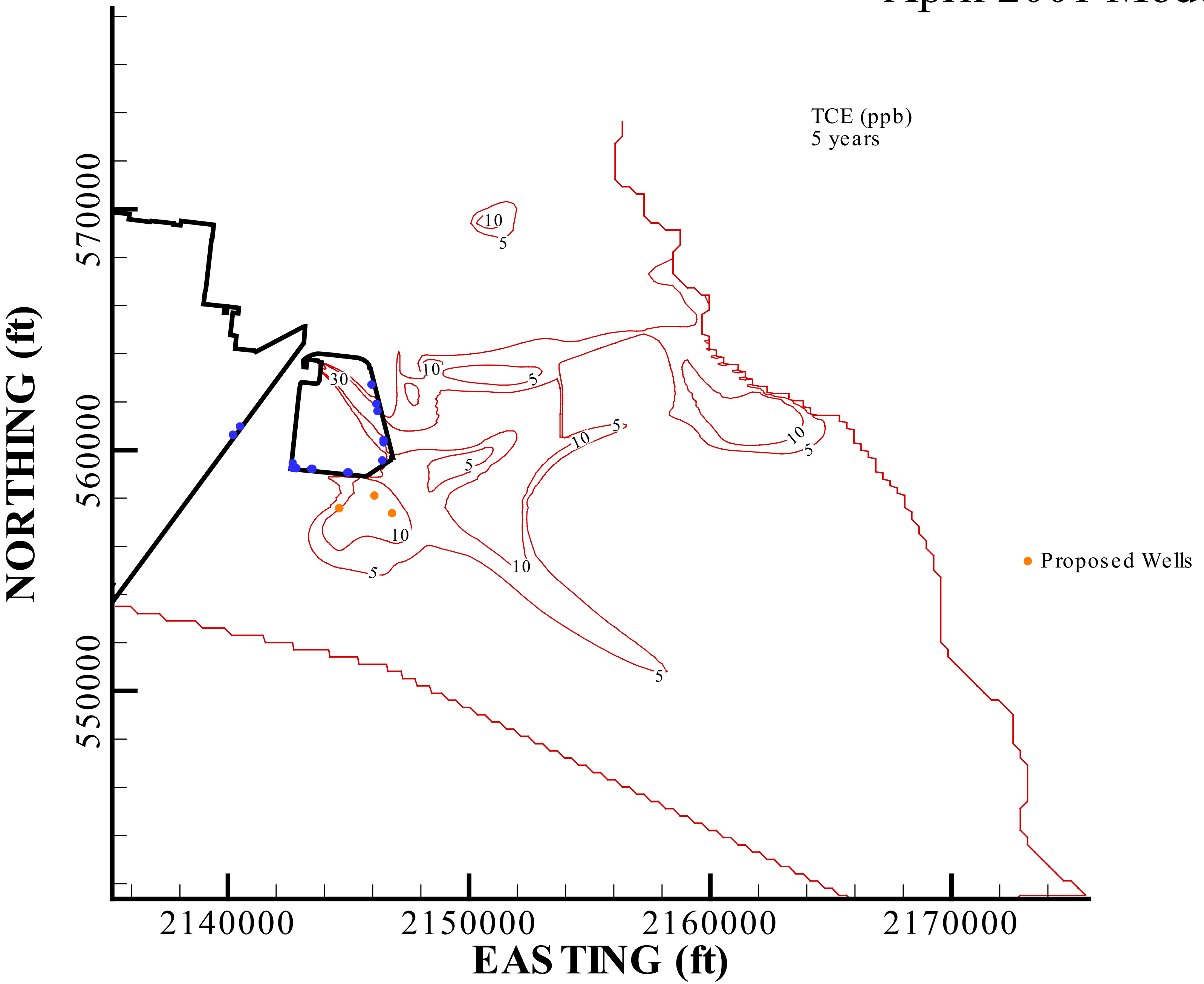
April 1999 Model



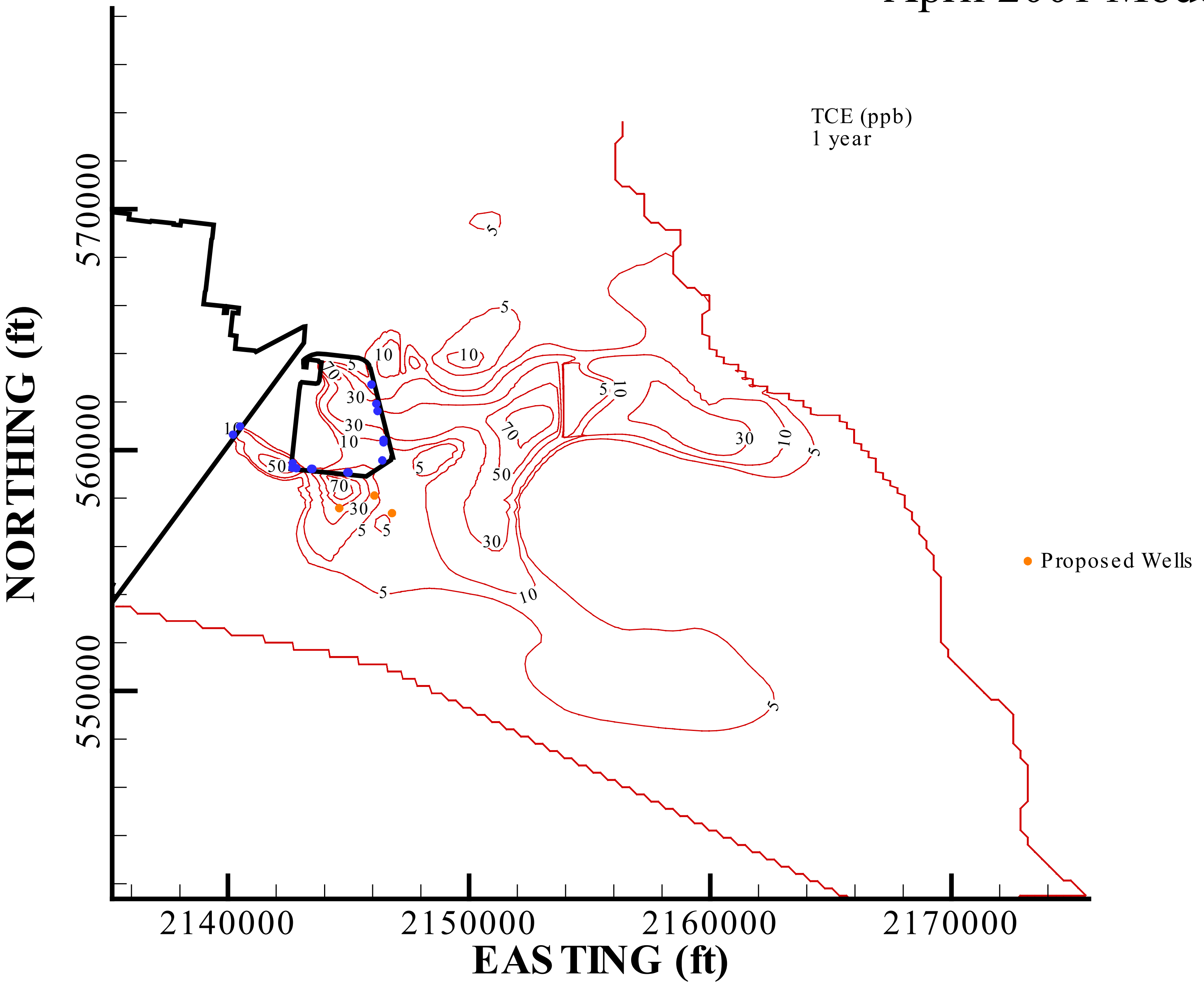


April 2001 Model
TCE (ppb)
10 years
Proposed Wells
NORTHING (ft)
EASTING (ft)
570000
560000
550000
2140000
2150000
2160000
2170000
5
5
5
5
5
5

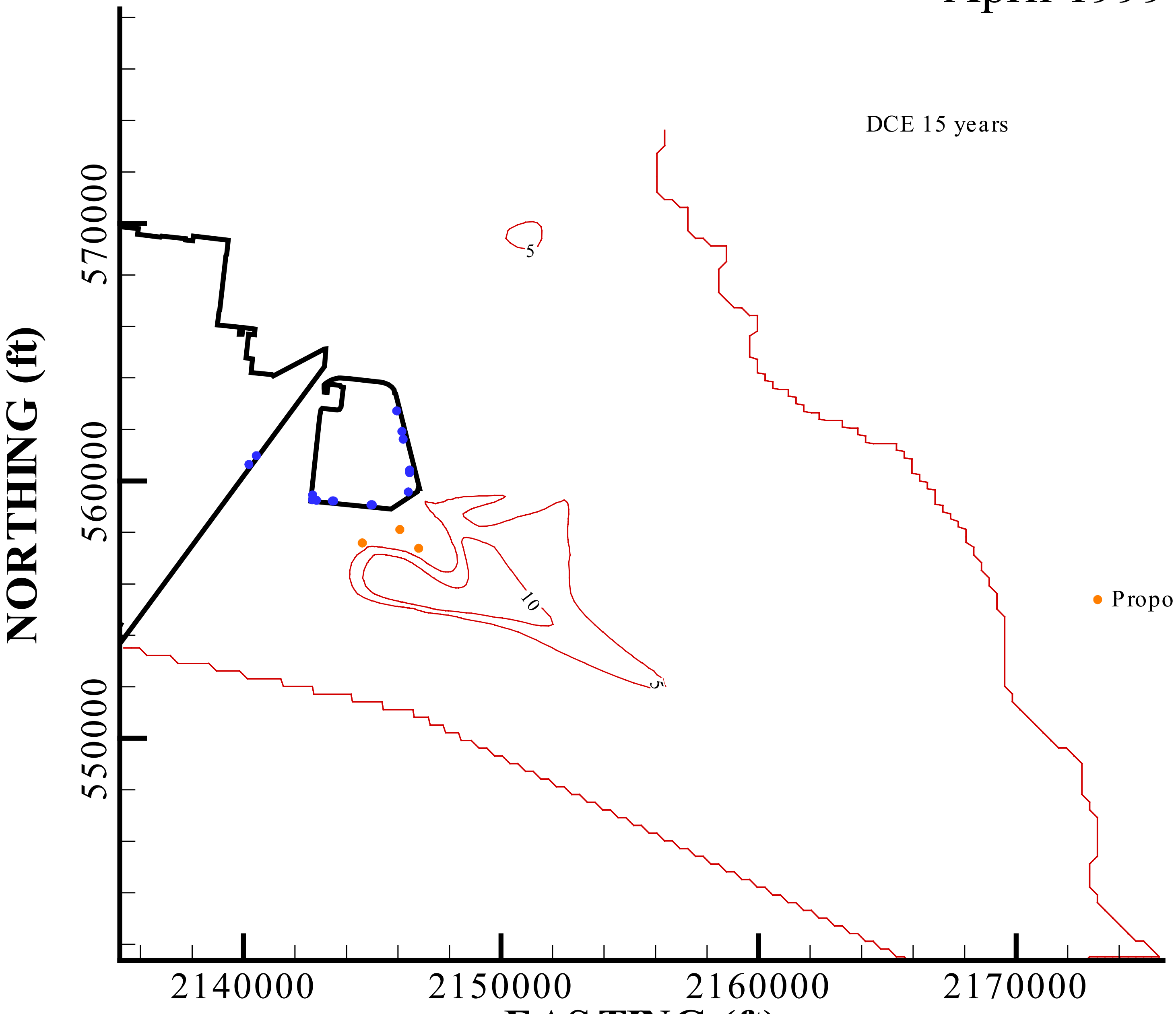
April 2001 Model

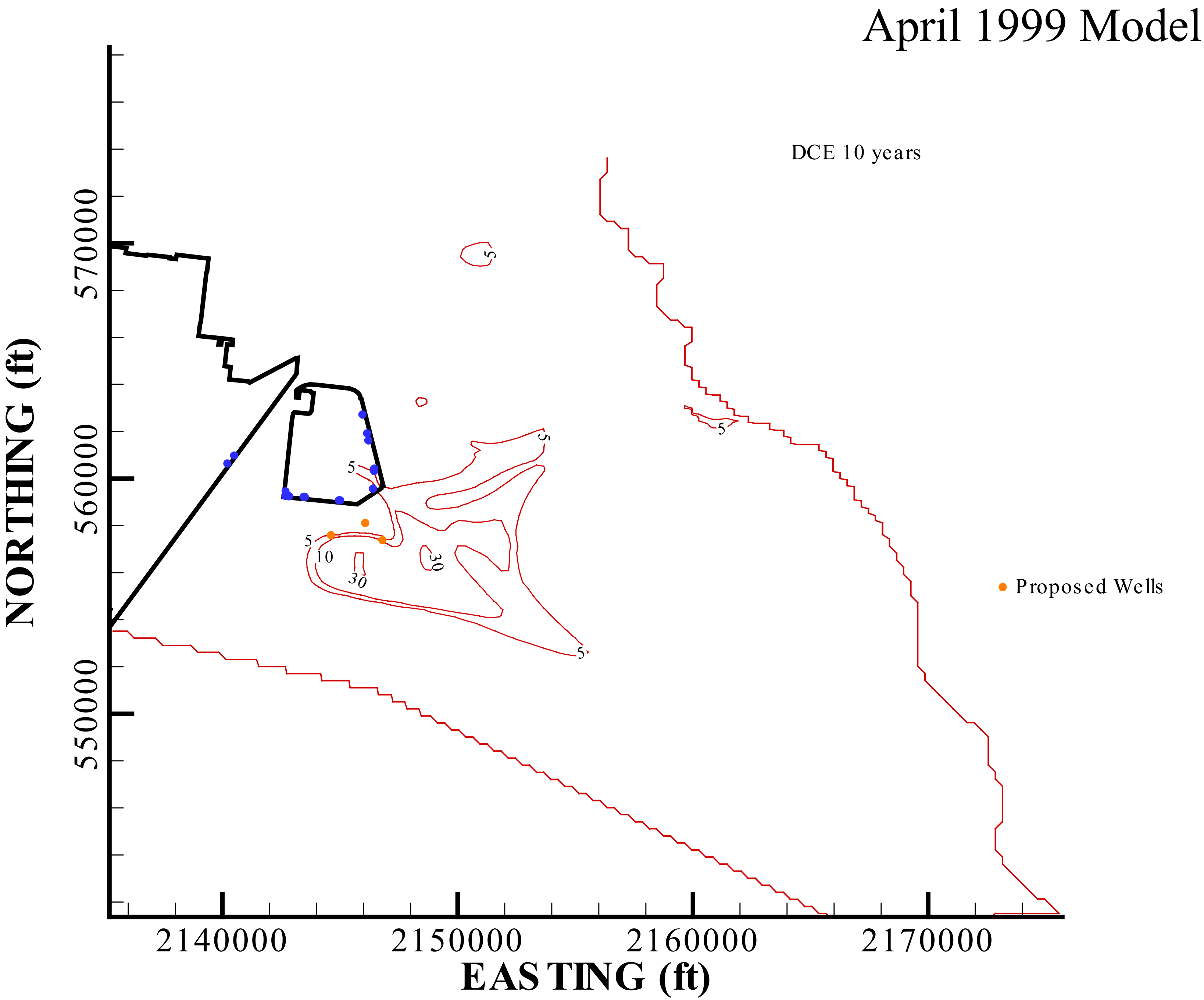


April 2001 Model

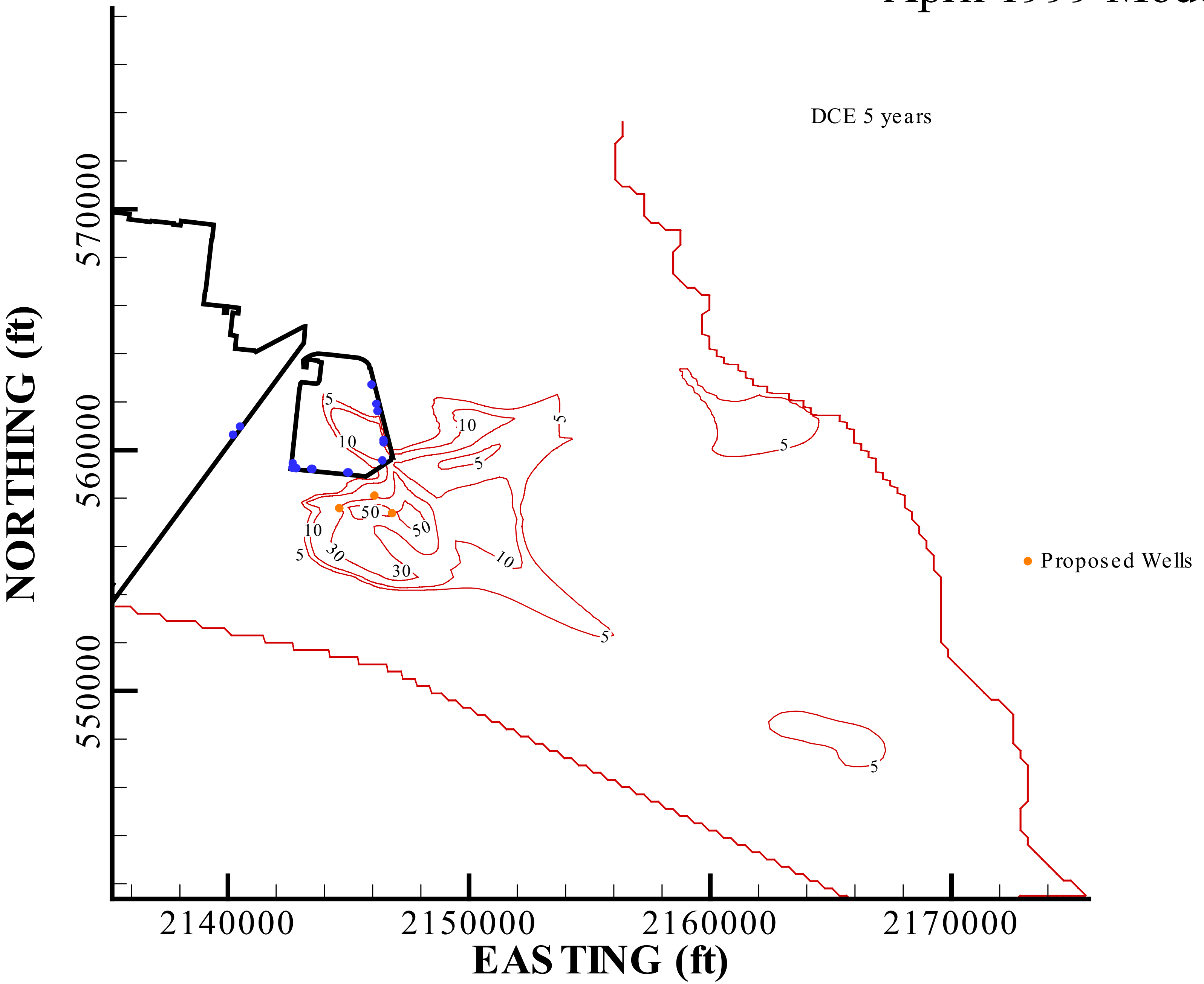


April 1999 Model

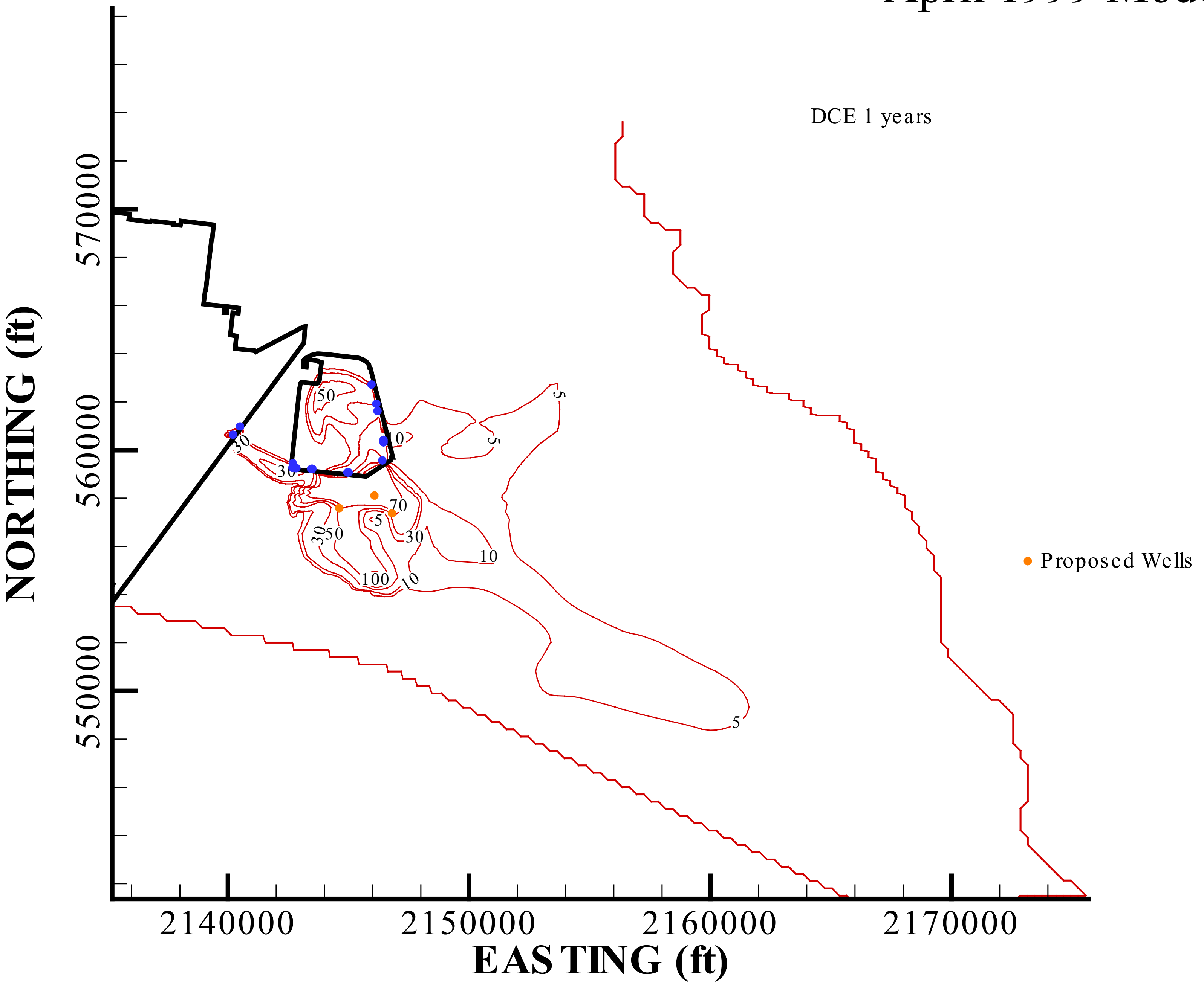



April 1999 Model
DCE 10 years
Proposed Wells
NORTHING (ft)
EASTING (ft)
5700000
5600000
5500000
2140000
2150000
2160000
2170000
5
10
30

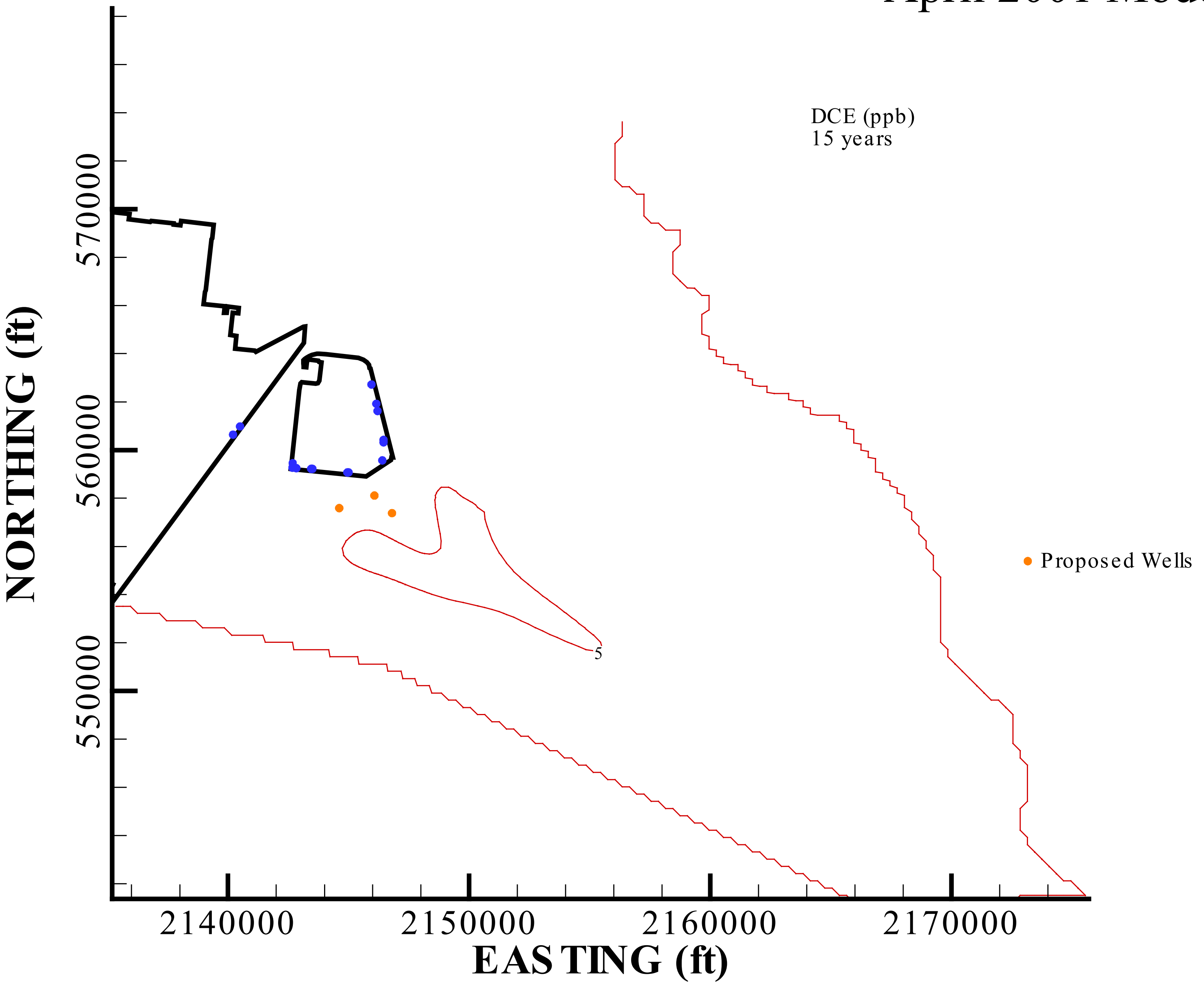
April 1999 Model



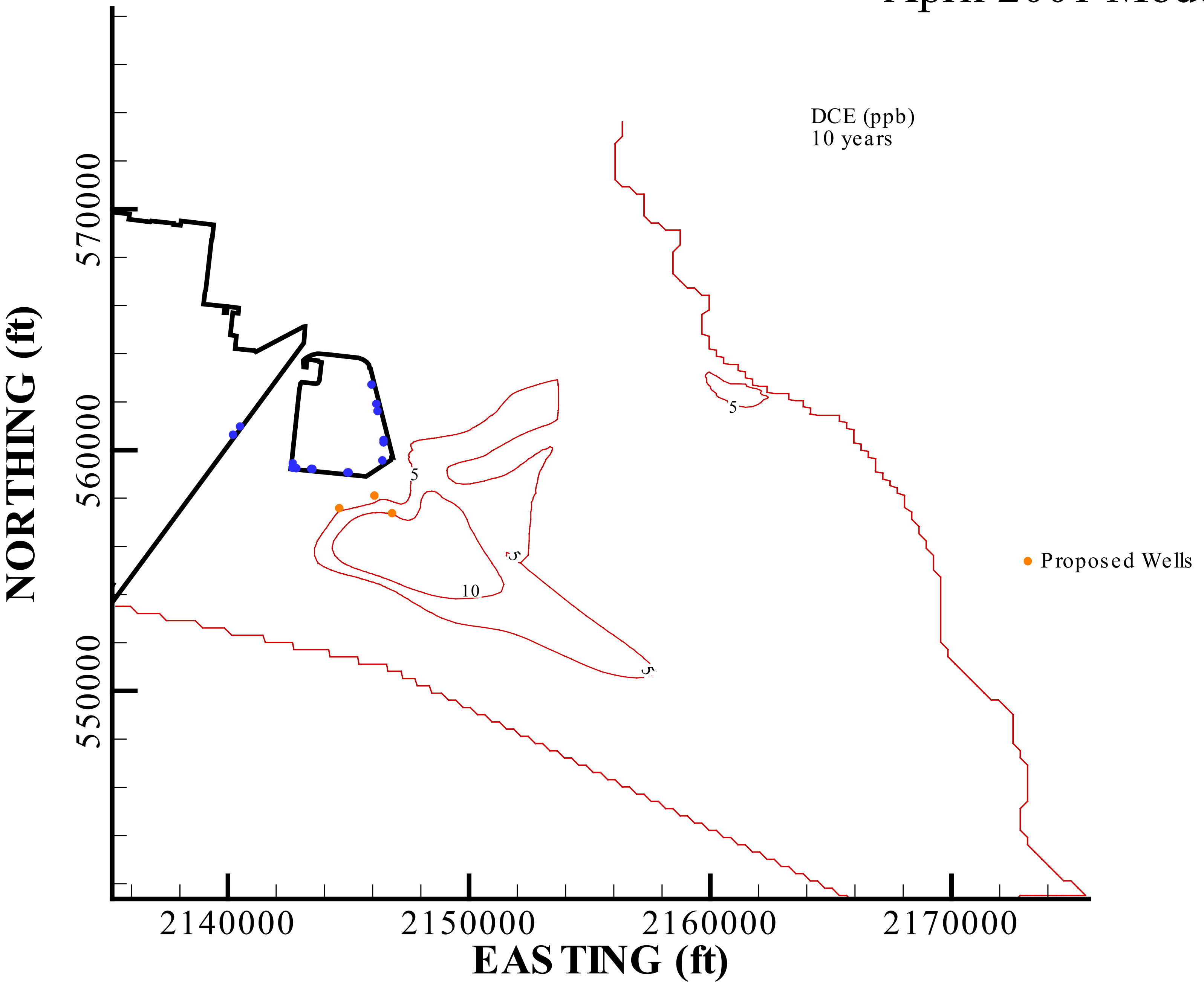
April 1999 Model



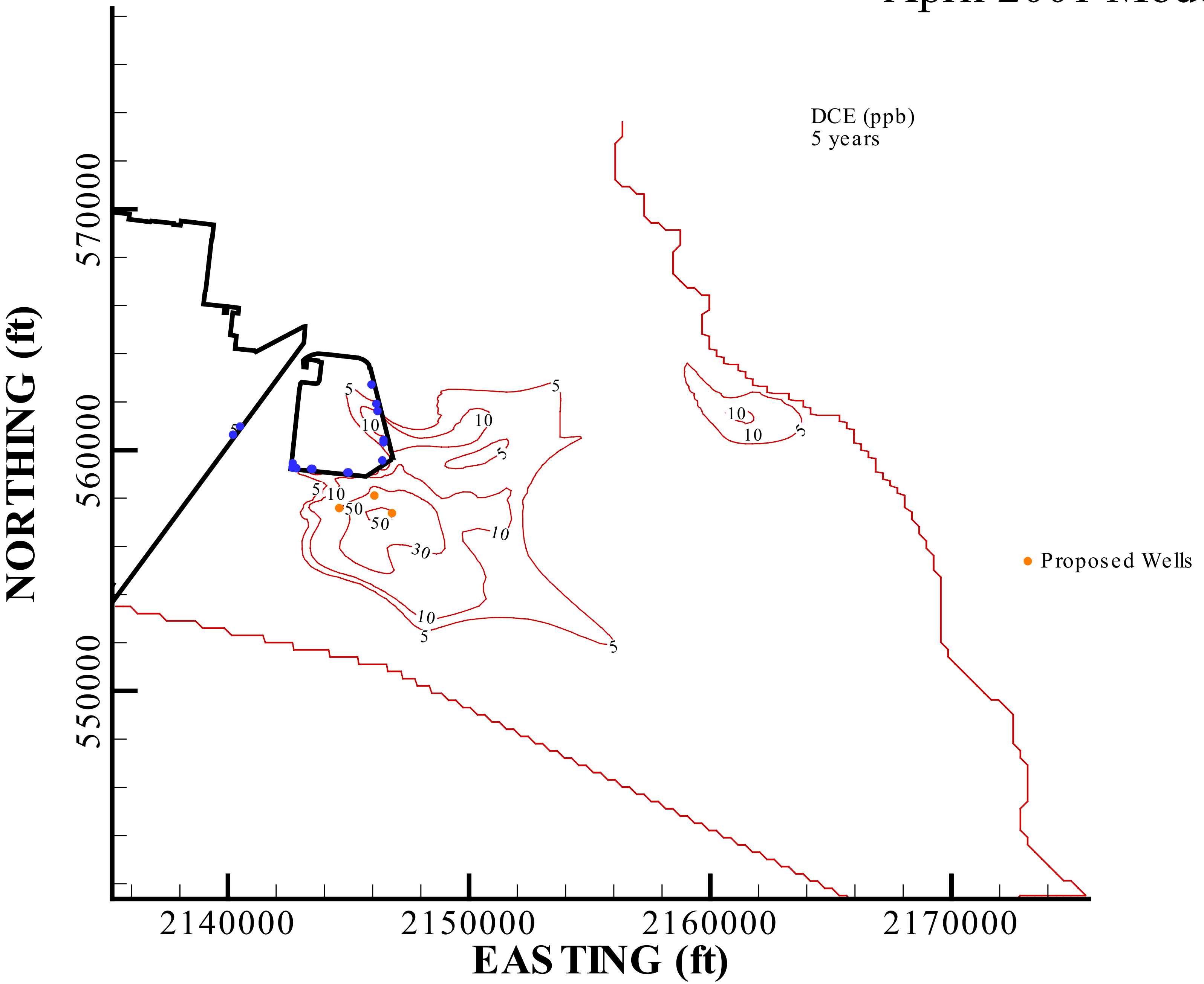
April 2001 Model



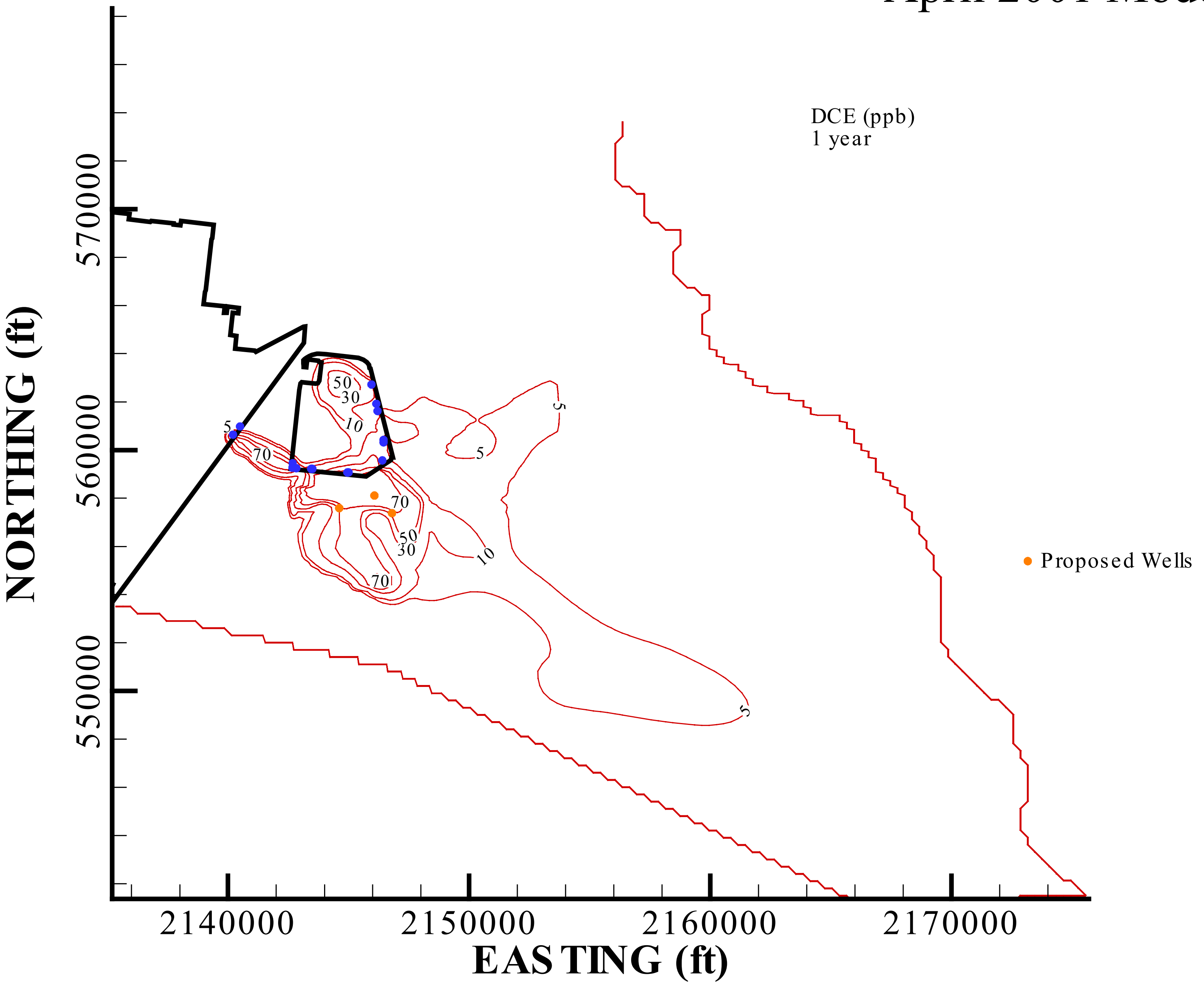
April 2001 Model



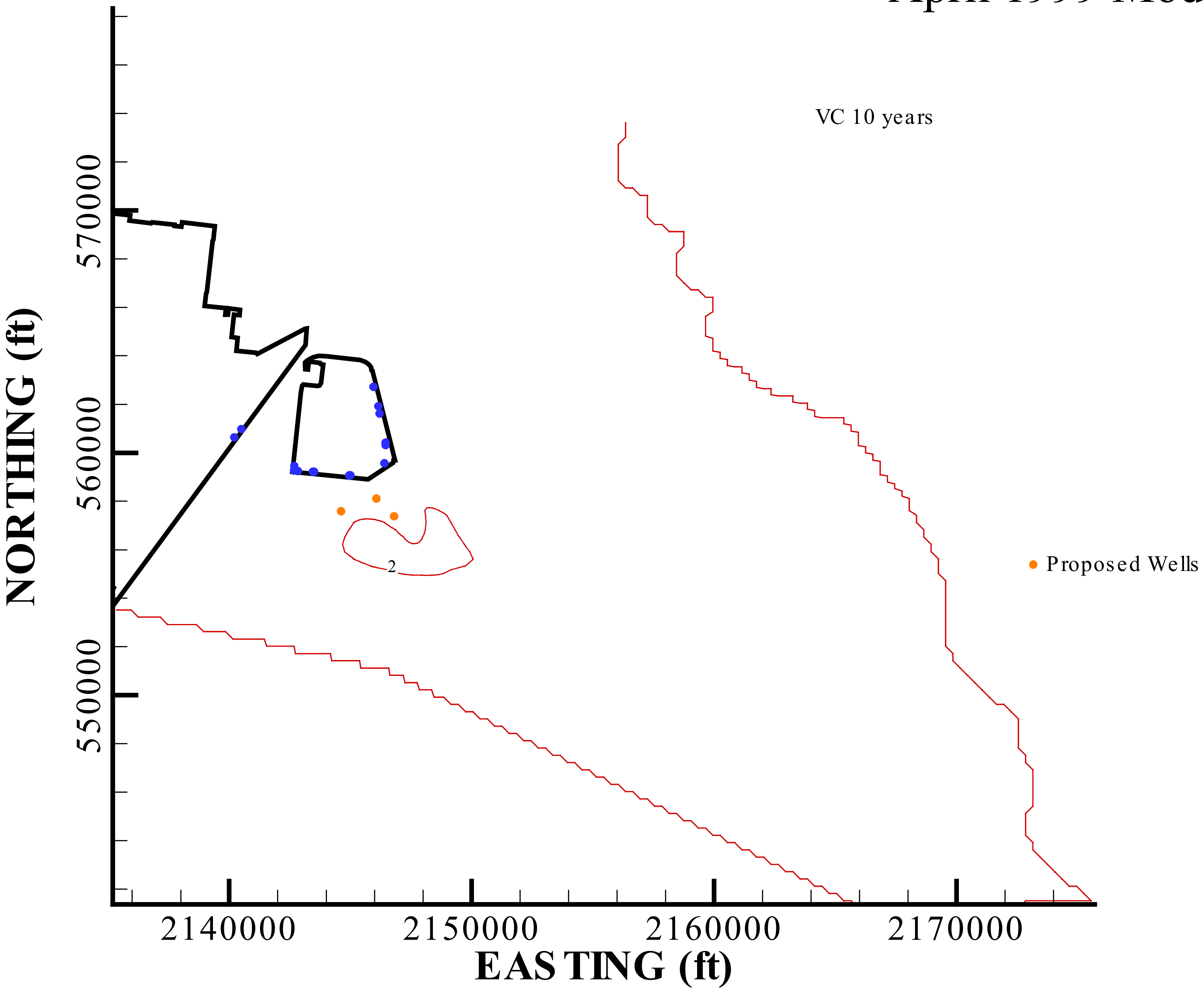
April 2001 Model



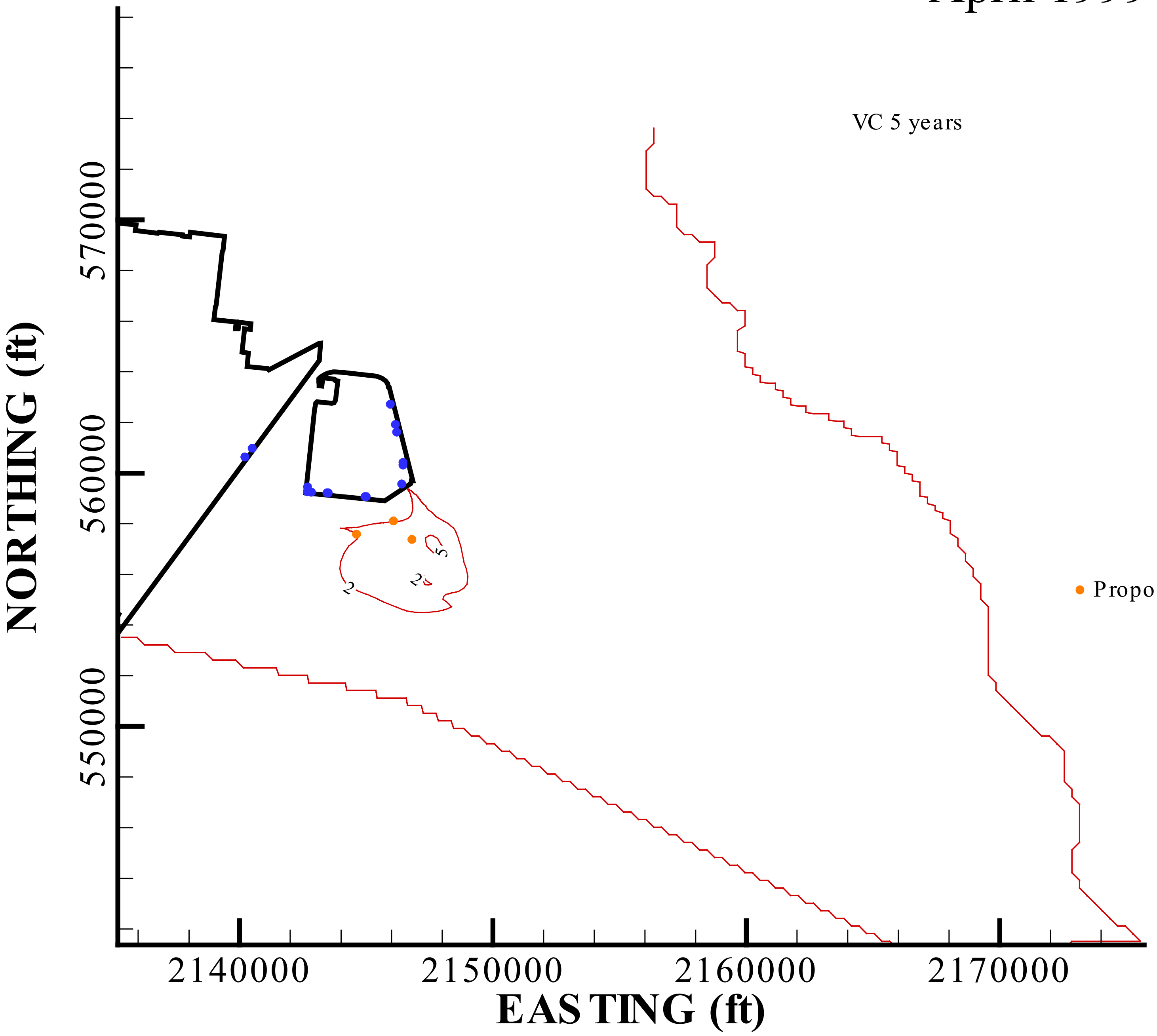
April 2001 Model



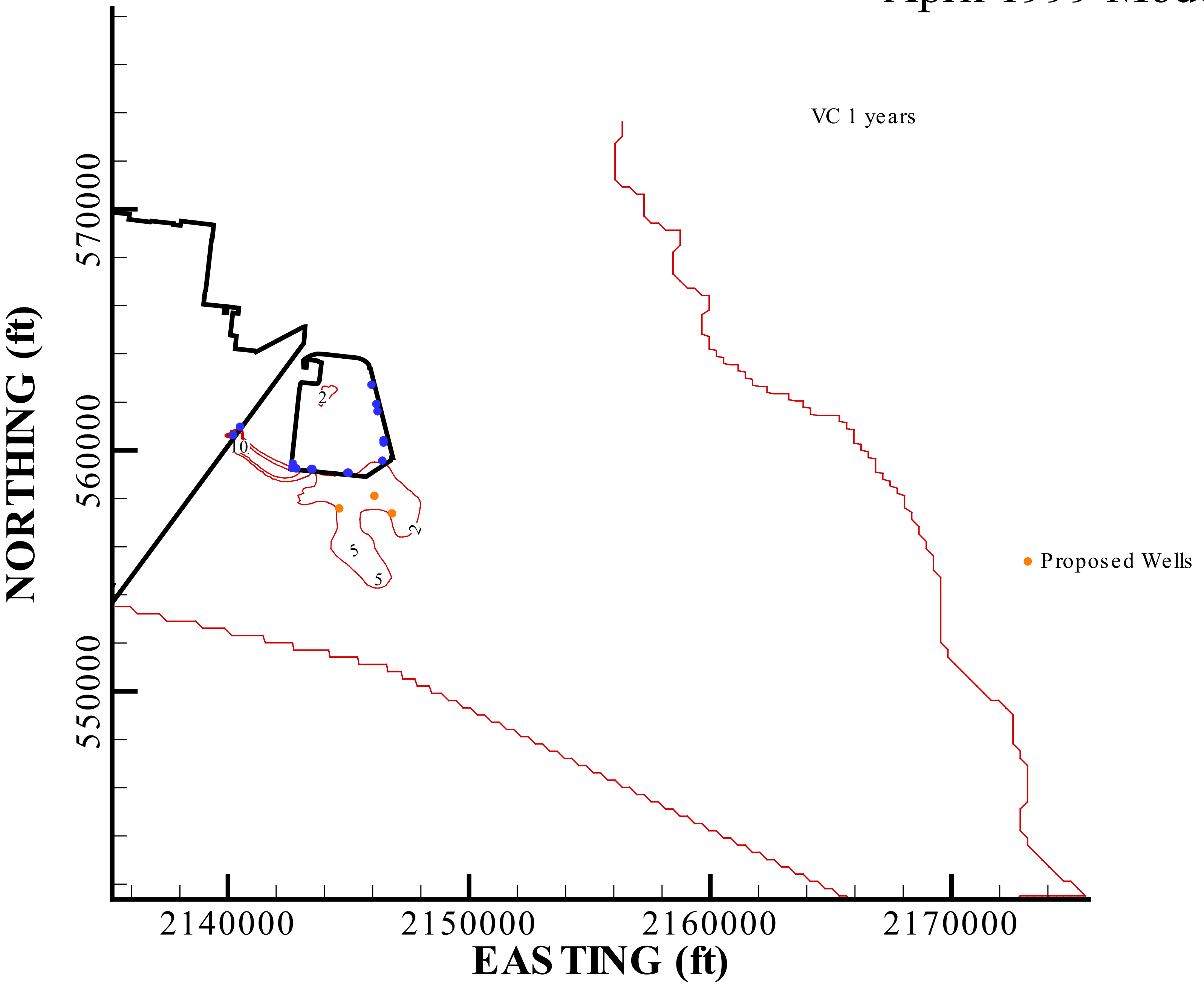
April 1999 Model



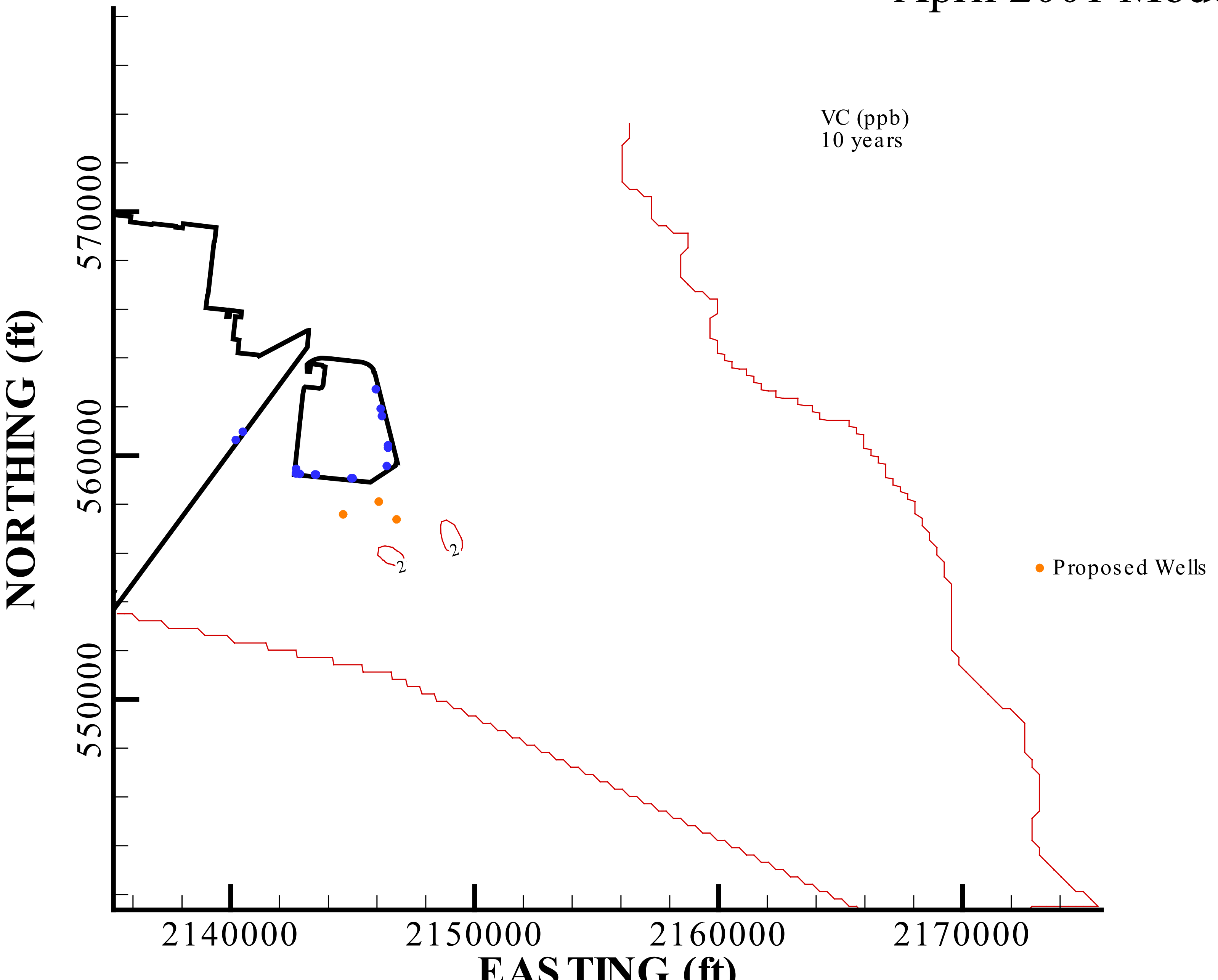
April 1999 Model



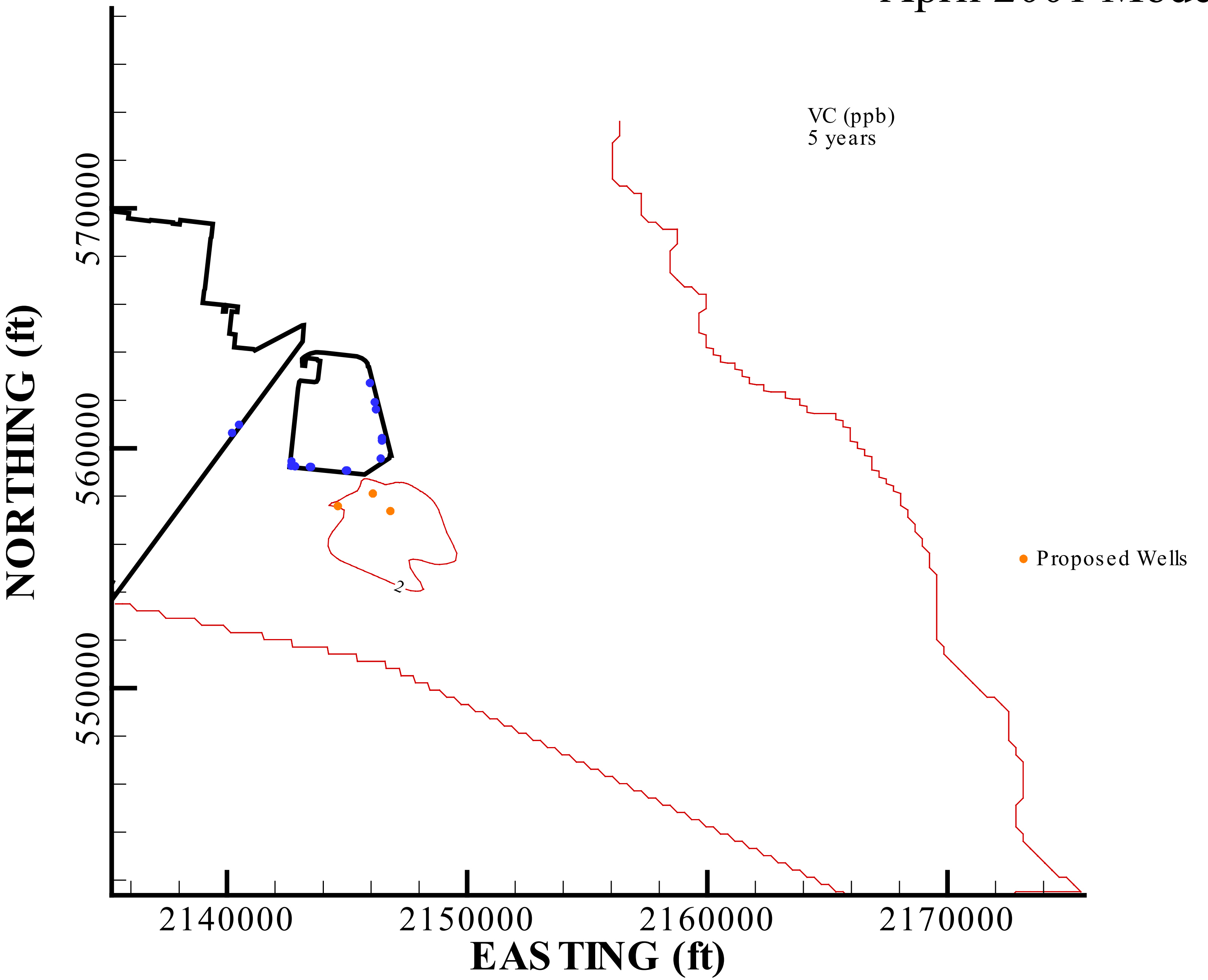
April 1999 Model



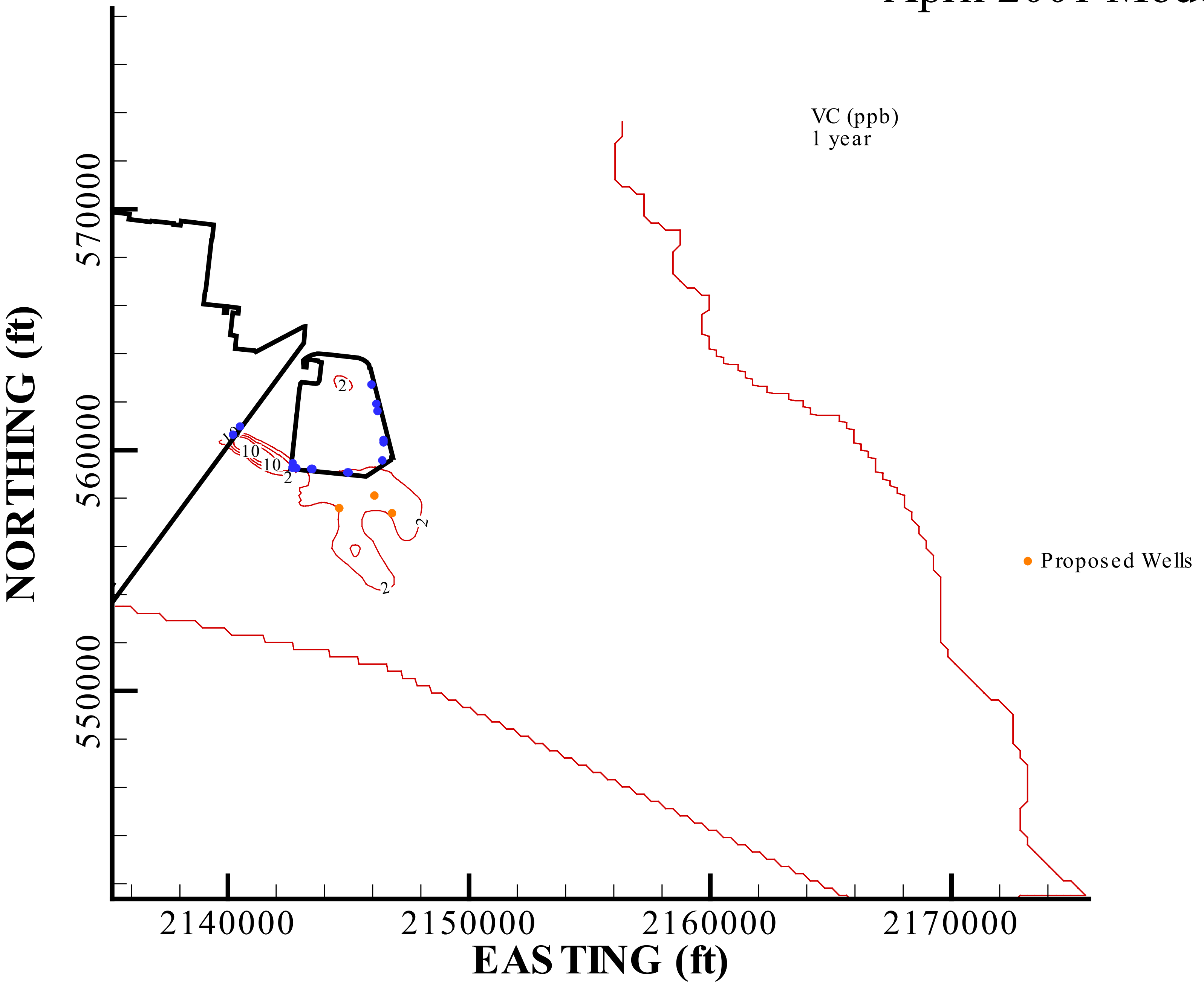
April 2001 Model



April 2001 Model



April 2001 Model



APPENDIX B
Trend Analyses

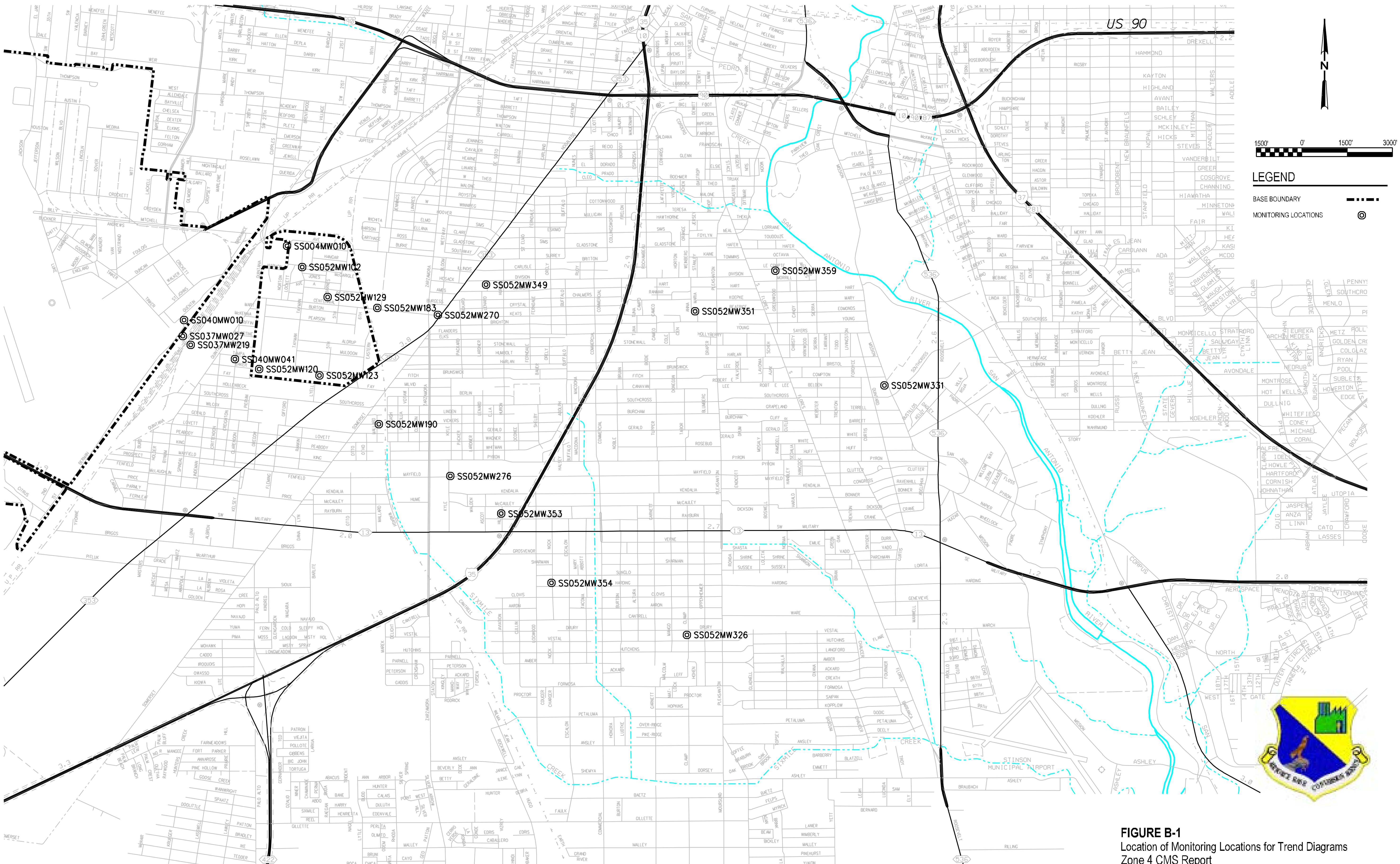


FIGURE B-1
Location of Monitoring Locations for Trend Diagrams
Zone 4 CMS Report
Kelly Air Force Base, Texas

CH2MHILL

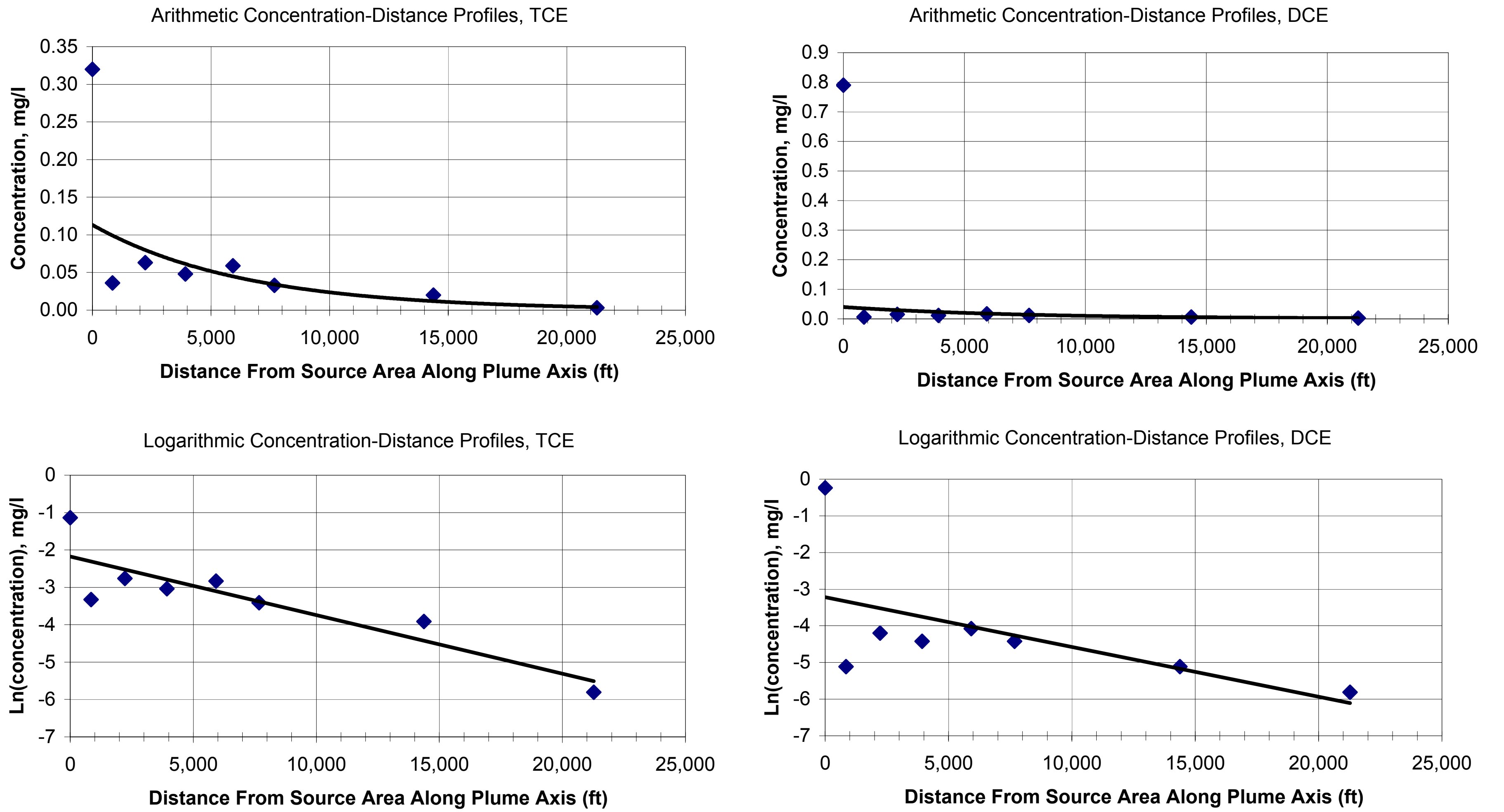


Figure B-2
Concentration Versus Distance for TCE and DCE in the SS051 Plume
Zone 4 CMS, Kelly AFB, TX

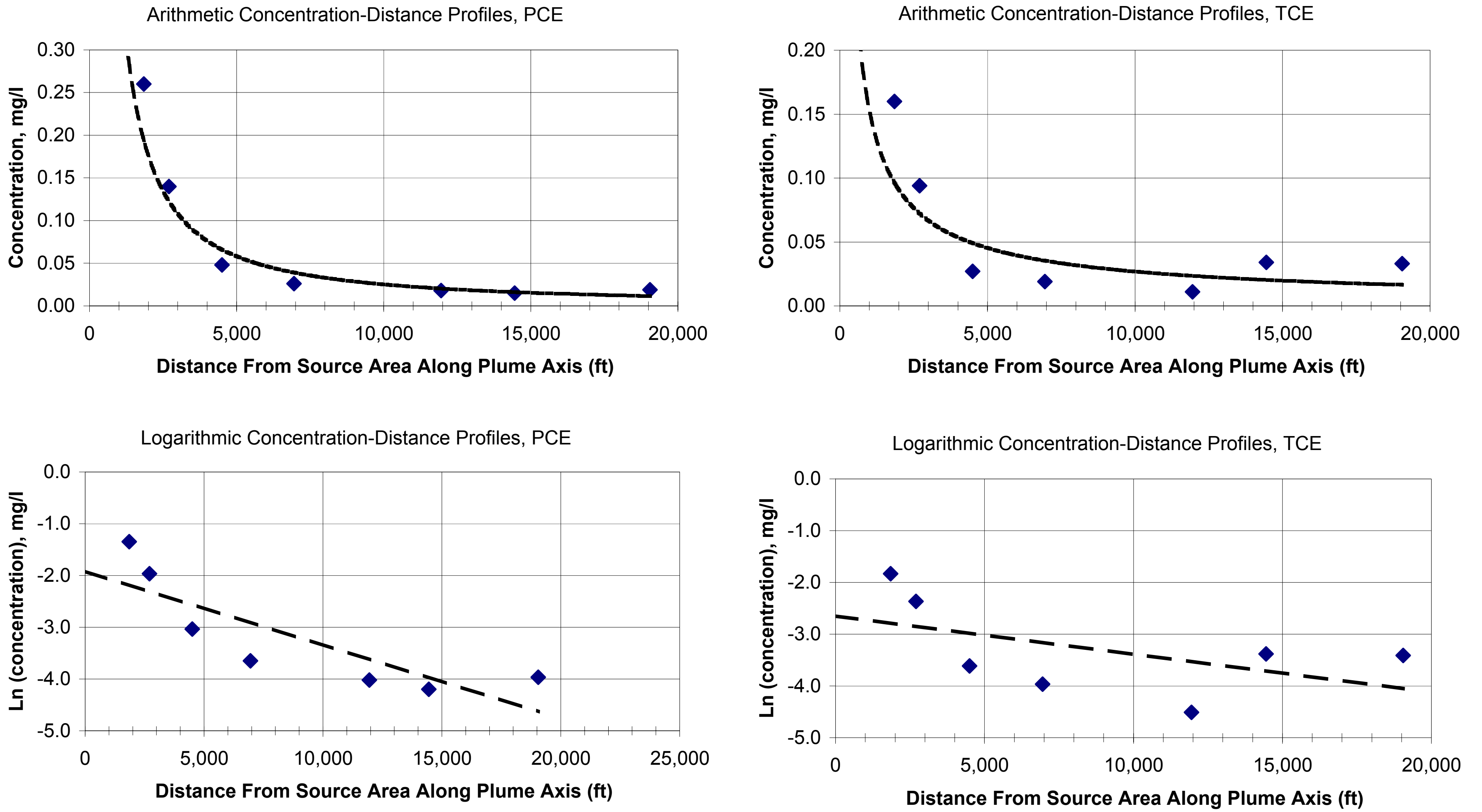


Figure B-3
Concentration Versus Distance for PCE and TCE in the MP Plume
Zone 4 CMS, Kelly AFB, TX

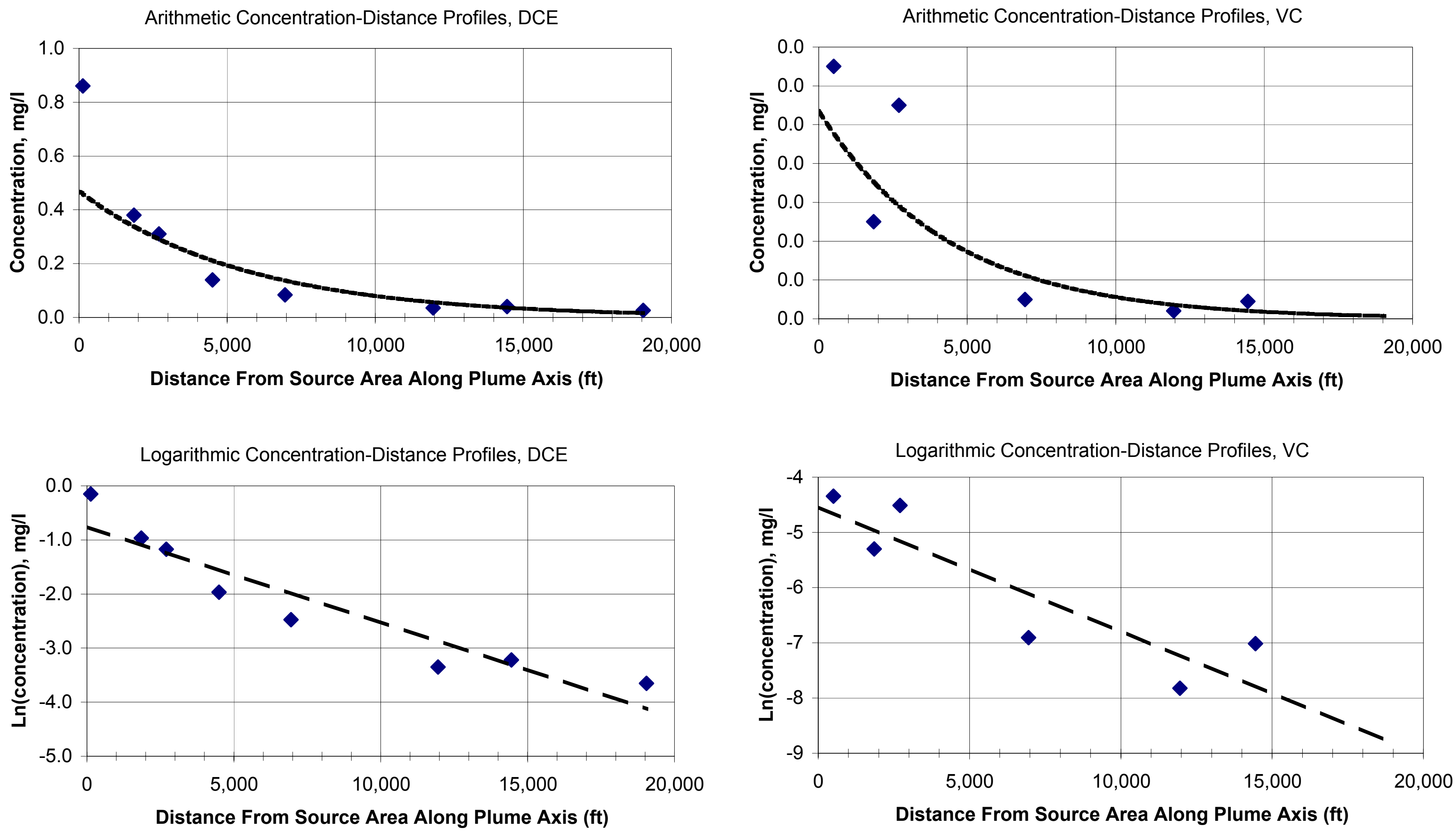


Figure B-4
Concentration Versus Distance for DCE and VC in the MP Plume
Zone 4 CMS, Kelly AFB, TX

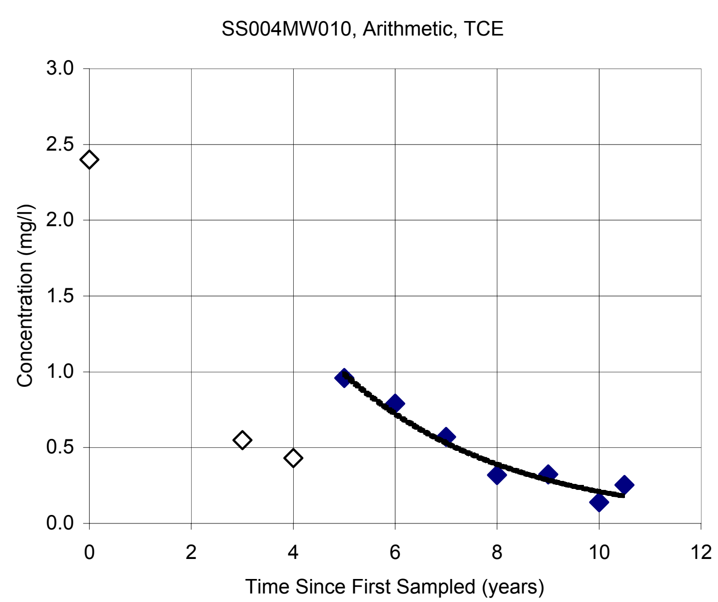
SS004MW010

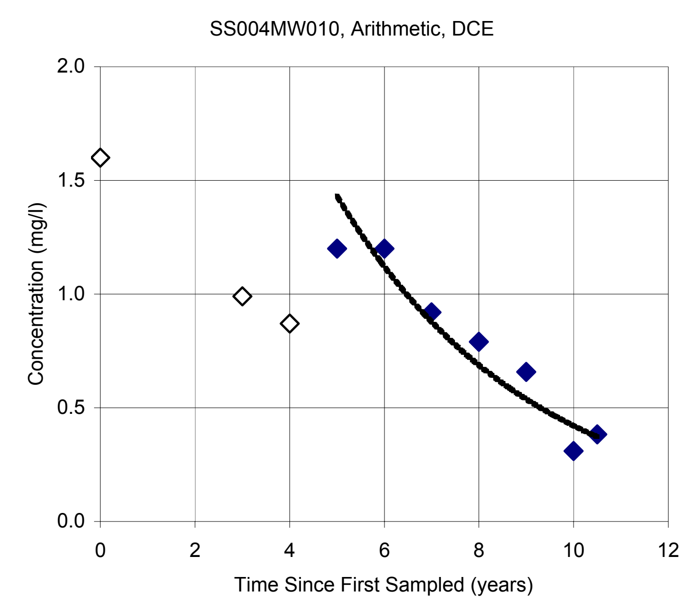
	Years Since First Sampled	PCE	TCE	DCE	VC
1991	0	No Data	2.4	1.6	0.032
1992	1				
1993	2				
1994	3	0.0025	0.55	0.99	0.029
1995	4	0.0025	0.43	0.87	0.023
1996	5		0.96	1.2	0.025
1997	6		0.79	1.2	0.025
1998	7		0.57	0.92	0.025
1999	8	0.0005	0.32	0.79	0.012
2000	9	0.00024	0.324	0.658	0.0018
2001	10	0.0005	0.14	0.31	0.0005
2001	10.5	0.0005	0.254	0.38262	0.0005

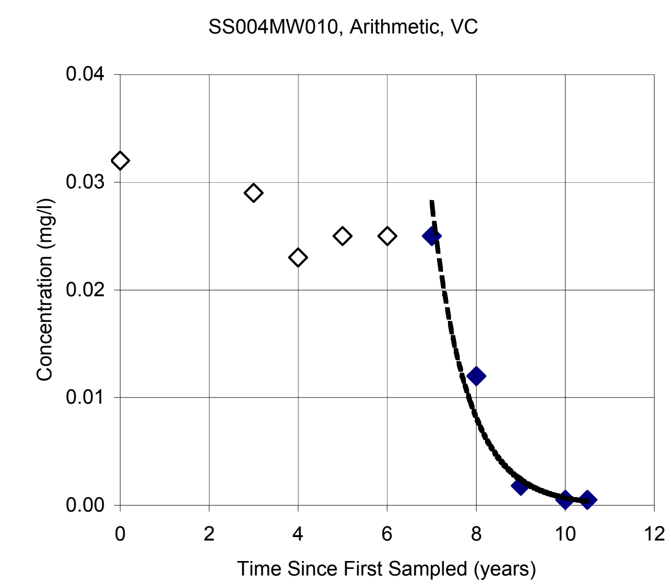
Ln of Sample Concentrations

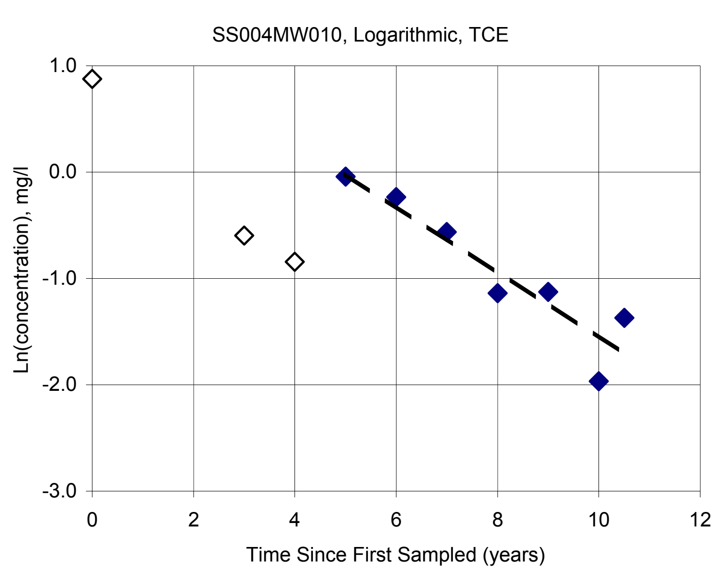
PCE	TCE	DCE	VC
No Data	0.875	0.470	-3.442
-5.991	-0.598	-0.010	-3.540
-5.991	-0.844	-0.139	-3.772
	-0.041	0.182	-3.689
	-0.236	0.182	-3.689
	-0.562	-0.083	-3.689
-7.601	-1.139	-0.236	-4.423
-8.335	-1.127	-0.419	-6.320
-7.601	-1.966	-1.171	-7.601
-7.601	-1.370	-0.961	-7.601

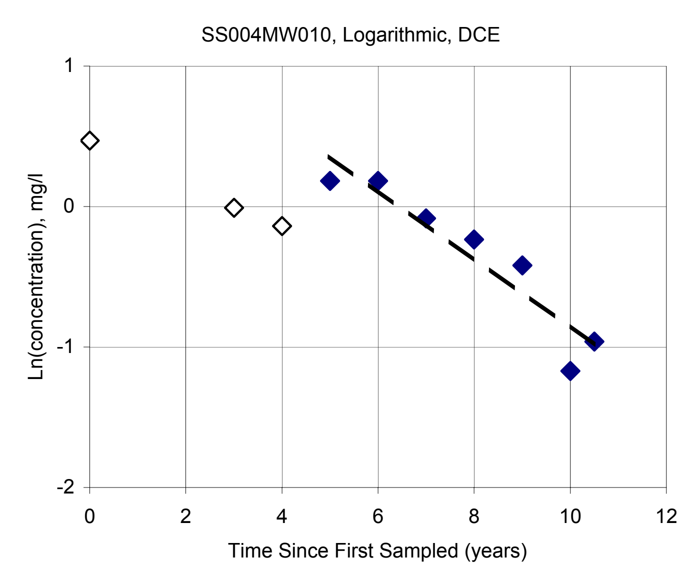
½ Detection Limit or ½ 'U' qualified value

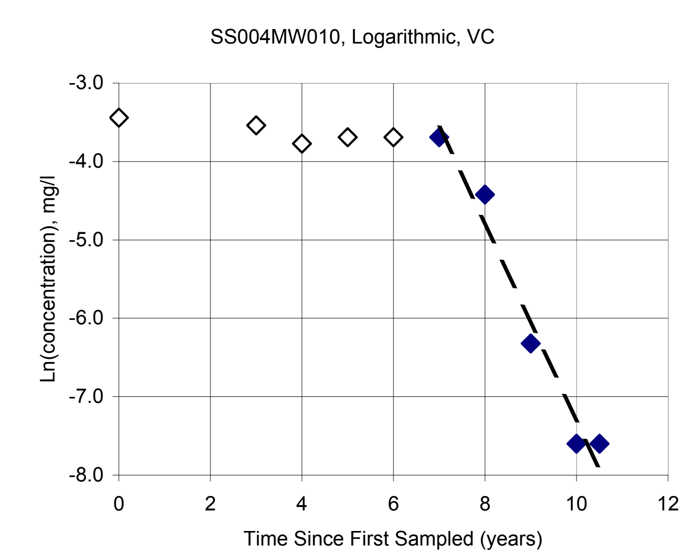












Regression and Mann-Kendall analyses use data shown as solid symbols.

Figure B-5a
Concentration Versus Time Trends for Well SS004MW010 in the SS051 Plume
Zone 4 CMS, Kelly AFB, TX

SS004MW010	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8	Event 9	Event 10	Sum of
TCE Concentration (mg/l)	2.4	0.55	0.43	**0.96**	**0.79**	**0.57**	**0.32**	**0.324**	**0.14**	**0.254**	Rows
Comparison to Event 1											0
Comparison to Event 2											0
Comparison to Event 3											0
Comparison to Event 4					-1	-1	-1	-1	-1	-1	-6
Comparison to Event 5						-1	-1	-1	-1	-1	-5
Comparison to Event 6							-1	-1	-1	-1	-4
Comparison to Event 7								1	-1	-1	-1
Comparison to Event 8									-1	-1	-2
Comparison to Event 9										1	1
										Mann-Kendall Statistic (S)	**-17**
										Trend Present (≥90% Confidence)	**Yes**

SS004MW010	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8	Event 9	Event 10	Sum of
DCE Concentration (mg/l)	1.6	0.99	0.87	**1.2**	**1.2**	**0.92**	**0.79**	**0.658**	**0.31**	**0.38262**	Rows
Comparison to Event 1											0
Comparison to Event 2											0
Comparison to Event 3											0
Comparison to Event 4					0	-1	-1	-1	-1	-1	-5
Comparison to Event 5						-1	-1	-1	-1	-1	-5
Comparison to Event 6							-1	-1	-1	-1	-4
Comparison to Event 7								-1	-1	-1	-3
Comparison to Event 8									-1	-1	-2
Comparison to Event 9										1	1
										Mann-Kendall Statistic (S)	**-18**
										Trend Present (≥90% Confidence)	**Yes**

SS004MW010	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8	Event 9	Event 10	Sum of
VC Concentration (mg/l)	0.032	0.029	0.023	0.025	0.025	**0.025**	**0.012**	**0.0018**	**0.0005**	**0.0005**	Rows
Comparison to Event 1											0
Comparison to Event 2											0
Comparison to Event 3											0
Comparison to Event 4											0
Comparison to Event 5											0
Comparison to Event 6							-1	-1	-1	-1	-4
Comparison to Event 7								-1	-1	-1	-3
Comparison to Event 8									-1	-1	-2
Comparison to Event 9										0	0
										Mann-Kendall Statistic (S)	**-9**
										Trend Present (≥90% Confidence)	**Yes**

S<0 Deminishing Concentration Trend
S>0 Expanding Concentration Trend

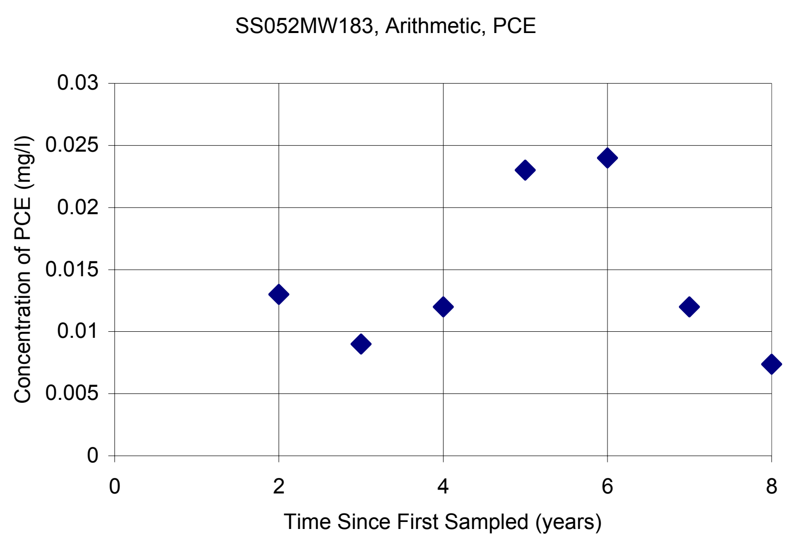
0.016 data used in trend analyses

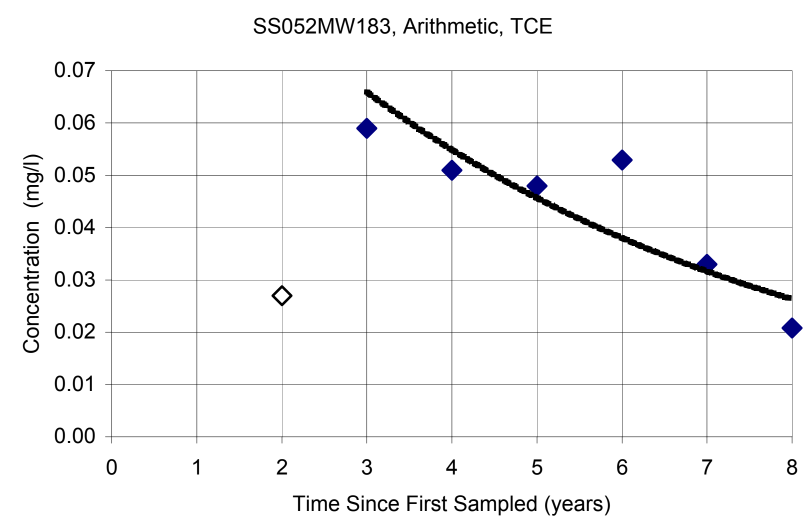
Figure B-5b
Mann-Kendall Analyses for Well SS004MW010 in the SS051 Plume
Zone 4 CMS, Kelly AFB, TX

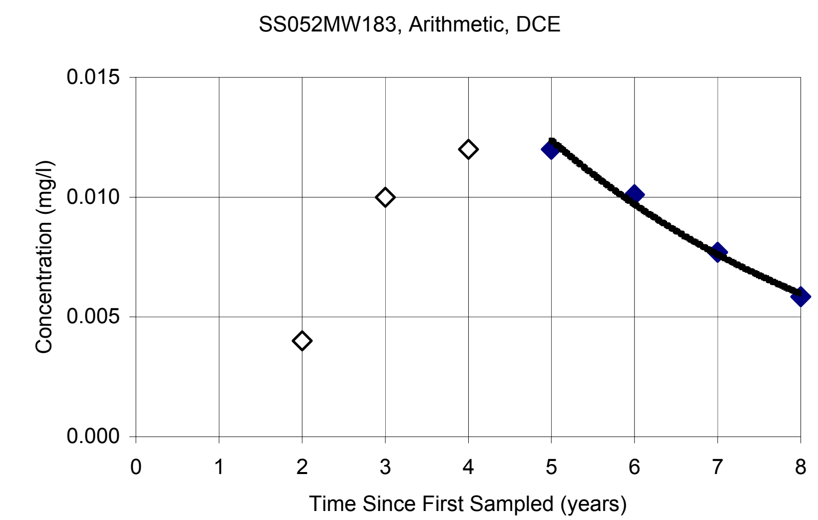
SS052MW183

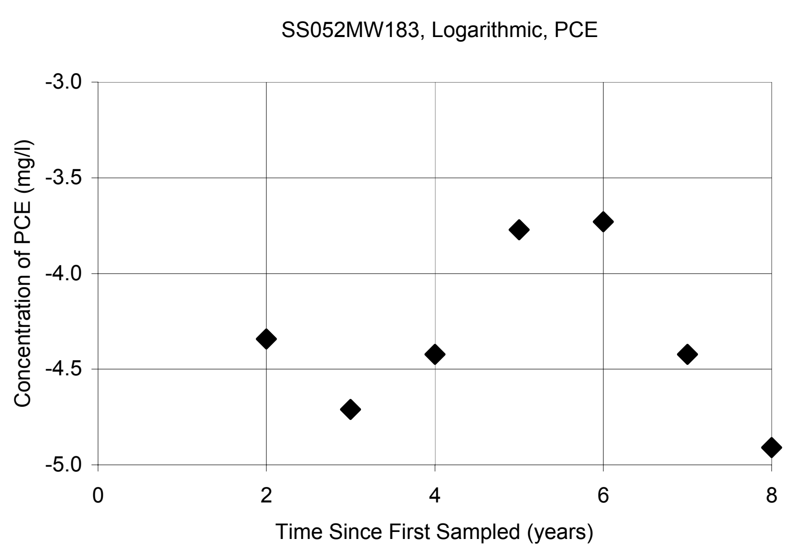
	Years Since First	PCE	TCE	DCE	VC	Ln of Sample Concentrations PCE	TCE	DCE	VC
1994	0								
1995	1								
1996	2	0.013	0.027	0.004	0.001	-4.343	-3.612	-5.521	-6.908
1997	3	0.009	0.059	0.01	0.001	-4.711	-2.830	-4.605	-6.908
1998	4	0.012	0.051	0.012	0.001	-4.423	-2.976	-4.423	-6.908
1999	5	0.023	0.048	0.012	0.0005	-3.772	-3.037	-4.423	-7.601
2000	6	0.024	0.0529	0.0101	0.0005	-3.730	-2.939	-4.595	-7.601
2001	7	0.012	0.033	0.0077	0.0005	-4.423	-3.411	-4.867	-7.601
2001	8	0.00738	0.0208	0.00584	0.0005	-4.909	-3.873	-5.143	-7.601

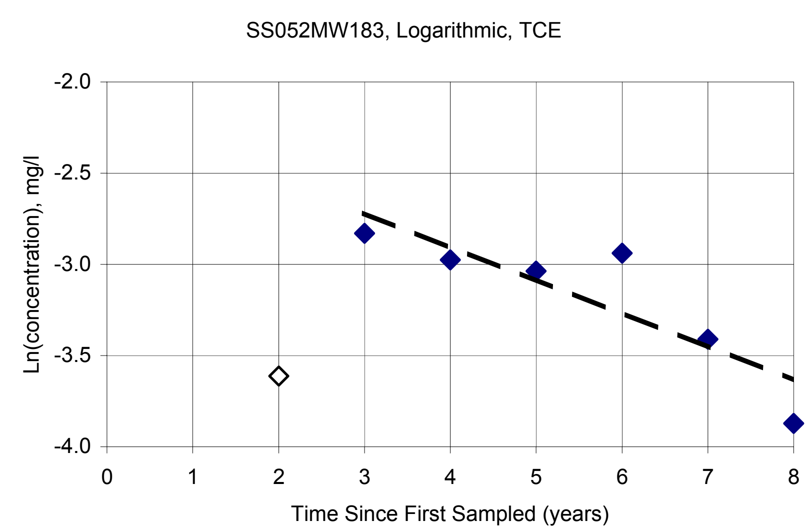
½ Detection Limit or ½ 'U' qualified value

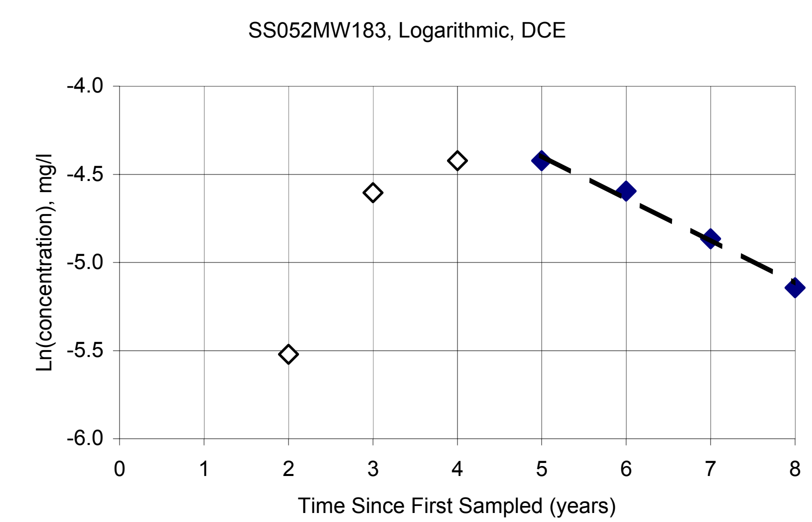












Regression and Mann-Kendall analyses use data shown as solid symbols.

Figure B-6a
Concentration Versus Time Trends for Well SS052MW183 in the SS051 Plume
Zone 4 CMS, Kelly AFB, TX

SS052MW183	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
PCE Concentration (mg/l)	**0.013**	**0.009**	**0.012**	**0.023**	**0.024**	**0.012**	**0.0074**	
Comparison to Event 1		-1	-1	1	1	-1	-1	-2
Comparison to Event 2			1	1	1	1	-1	3
Comparison to Event 3				1	1	0	-1	1
Comparison to Event 4					1	-1	-1	-1
Comparison to Event 5						-1	-1	-2
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-2**
							Trend Present (≥90% Confidence)	**No**
SS052MW183	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
TCE Concentration (mg/l)	0.027	**0.059**	**0.051**	**0.048**	**0.0529**	**0.033**	**0.0208**	
Comparison to Event 1								
Comparison to Event 2			-1	-1	-1	-1	-1	-5
Comparison to Event 3				-1	1	-1	-1	-2
Comparison to Event 4					1	-1	-1	-1
Comparison to Event 5						-1	-1	-1
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-10**
							Trend Present (≥90% Confidence)	**Yes**
SS052MW183	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
DCE Concentration (mg/l)	0.004	0.01	0.012	**0.012**	**0.0101**	**0.0077**	**0.0058**	
Comparison to Event 1								
Comparison to Event 2								
Comparison to Event 3								
Comparison to Event 4					-1	-1	-1	-3
Comparison to Event 5						-1	-1	-2
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-6**
							Trend Present (≥90% Confidence)	**Yes**

S<0 Deminishing Concentration Trend
S>0 Expanding Concentration Trend

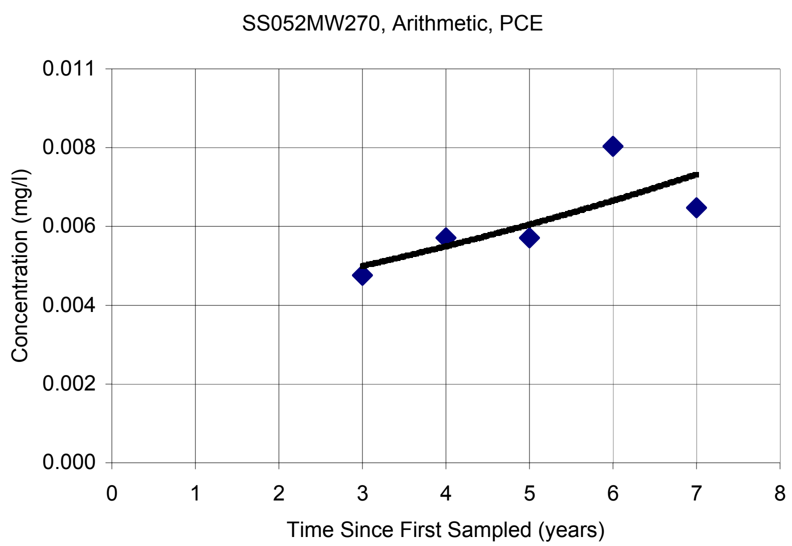
0.016 data used in trend analyses

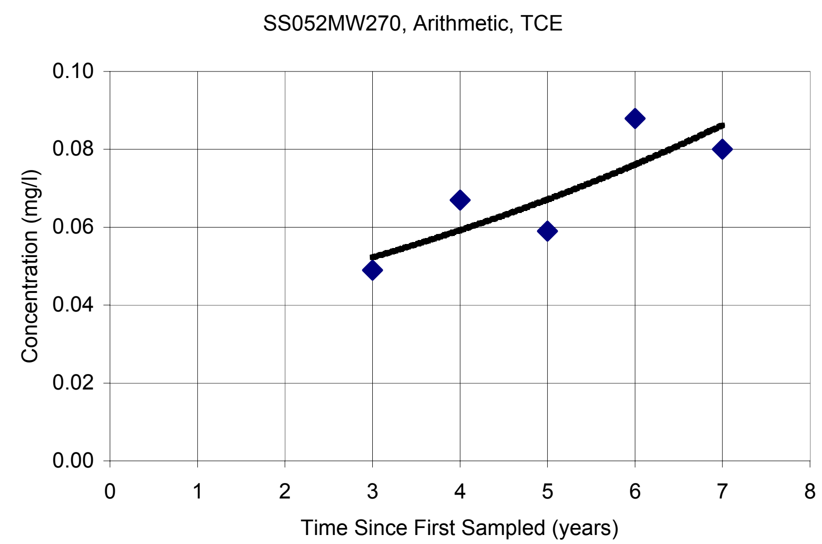
Figure B-6b
Mann-Kendall Analyses for Well SS052MW183 in the SS051 Plume
Zone 4 CMS, Kelly AFB, TX

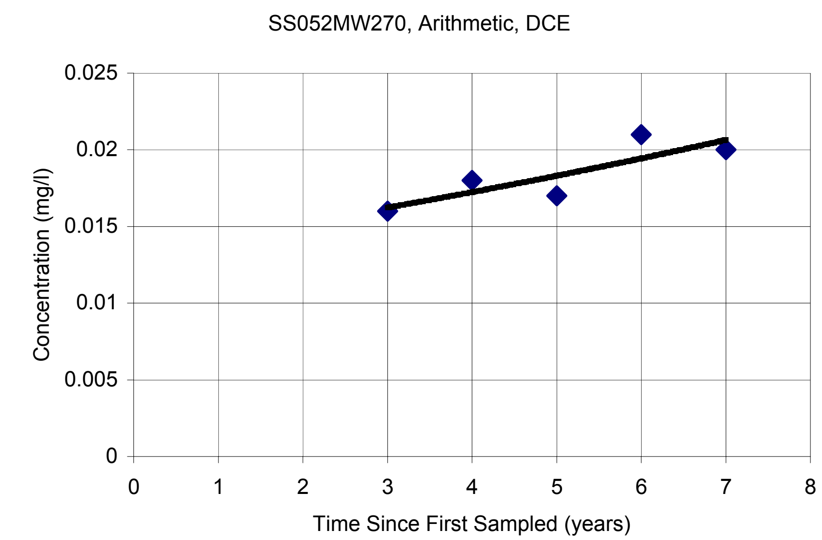
SS052MW270	Years Since First	PCE	TCE	DCE	VC	Ln PCE	Ln TCE	Ln DCE	Ln VC
1994	0								
1995	1								
1996	2								
1997	3	0.005	0.049	0.016	0.0005	-5.298	-3.016	-4.135	-7.601
1998	4	0.006	0.067	0.018	0.0025	-5.116	-2.703	-4.017	-5.991
1999	5	0.006	0.059	0.017	0.0005	-5.116	-2.830	-4.075	-7.601
2000	6	0.00844	0.0879	0.021	0.0005	-4.775	-2.432	-3.863	-7.601
2001	7	0.0068	0.08	0.02	0.0005	-4.991	-2.526	-3.912	-7.601

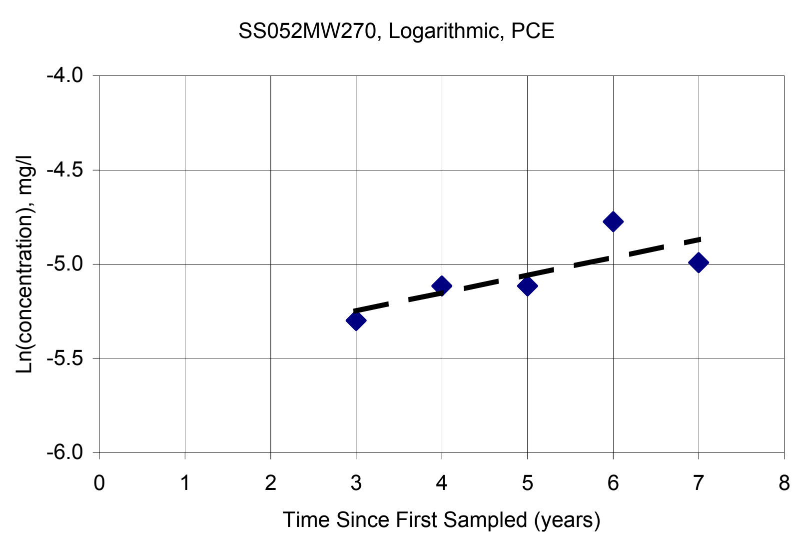
(Ln columns: Ln of Sample Concentrations)

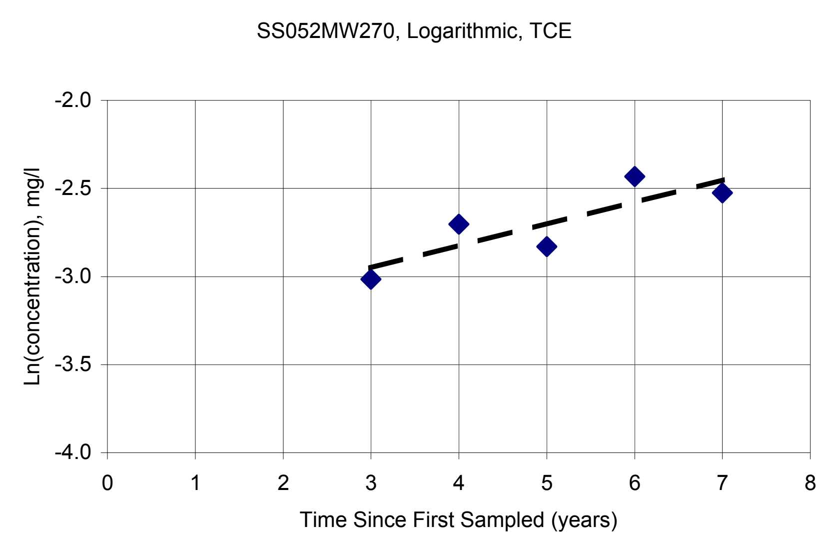
½ Detection Limit or ½ 'U' qualified value

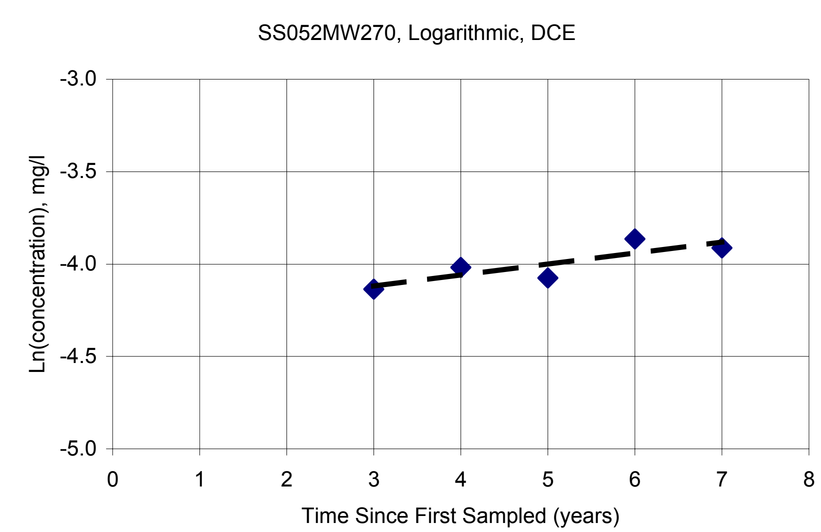












Regression and Mann-Kendall analyses use data shown as solid symbols.

Figure B-7a
Concentration Versus Time Trends for Well SS052MW270 in the SS051 Plume
Zone 4 CMS, Kelly AFB, TX

SS052MW270	Event 1	Event 2	Event 3	Event 4	Event 5	Sum of
PCE Concentration (mg/l)	**0.005**	**0.006**	**0.006**	**0.00844**	**0.0068**	Rows
Comparison to Event 1		1	1	1	1	4
Comparison to Event 2			0	1	1	2
Comparison to Event 3				1	1	2
Comparison to Event 4					-1	-1
					Mann-Kendall Statistic (S)	**7**
					Trend Present (≥90% Confidence)	**Yes**

SS052MW270	Event 1	Event 2	Event 3	Event 4	Event 5	Sum of
TCE Concentration (mg/l)	**0.049**	**0.067**	**0.059**	**0.0879**	**0.08**	Rows
Comparison to Event 1		1	1	1	1	4
Comparison to Event 2			-1	1	1	1
Comparison to Event 3				1	1	2
Comparison to Event 4					-1	-1
					Mann-Kendall Statistic (S)	**6**
					Trend Present (≥90% Confidence)	**No**

SS052MW270	Event 1	Event 2	Event 3	Event 4	Event 5	Sum of
DCE Concentration (mg/l)	**0.016**	**0.018**	**0.017**	**0.021**	**0.02**	Rows
Comparison to Event 1		1	1	1	1	4
Comparison to Event 2			-1	1	1	1
Comparison to Event 3				1	1	2
Comparison to Event 4					-1	-1
					Mann-Kendall Statistic (S)	**6**
					Trend Present (≥90% Confidence)	**No**

S<0 Deminishing Concentration Trend
S>0 Expanding Concentration Trend

0.016 data used in trend analyses

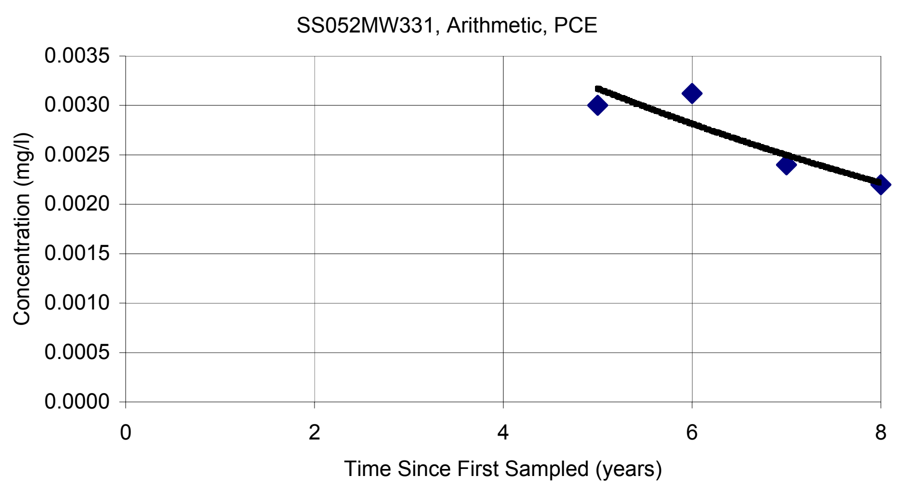
Figure B-7b
Mann-Kendall Analyses for Well SS052MW270 in the SS051 Plume
Zone 4 CMS, Kelly AFB, TX

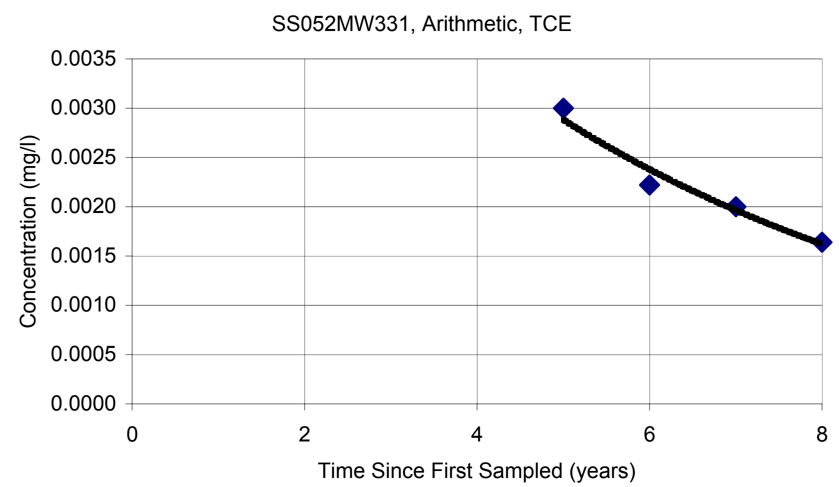
SS052MW331

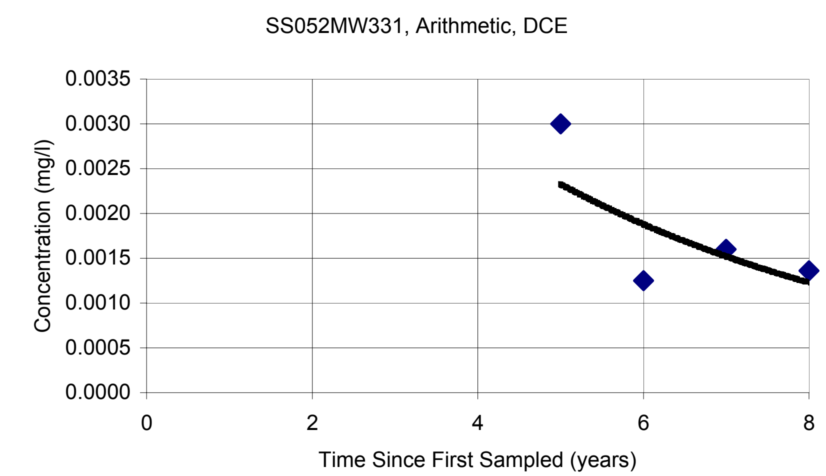
	Years Since First Sampled	PCE	TCE	DCE	VC	Ln PCE	Ln TCE	Ln DCE	Ln VC
1994	0								
1995	1								
1996	2								
1997	3								
1998	4								
1999	5	0.003	0.003	0.003	0.0005	-5.809	-5.809	-5.809	-7.601
2000	6	0.00312	0.00222	0.00125	0.0005	-5.770	-6.110	-6.685	-7.601
2001	7	0.0024	0.002	0.0016	0.0005	-6.032	-6.215	-6.438	-7.601
2001	8	0.0022	0.00164	0.00136	0.0005	-6.119	-6.413	-6.600	-7.601

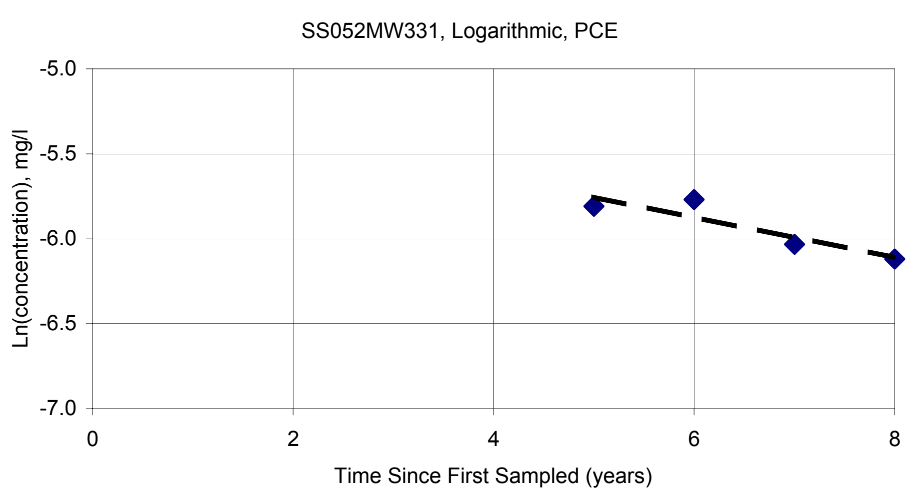
(Ln columns: Ln of Sample Concentrations)

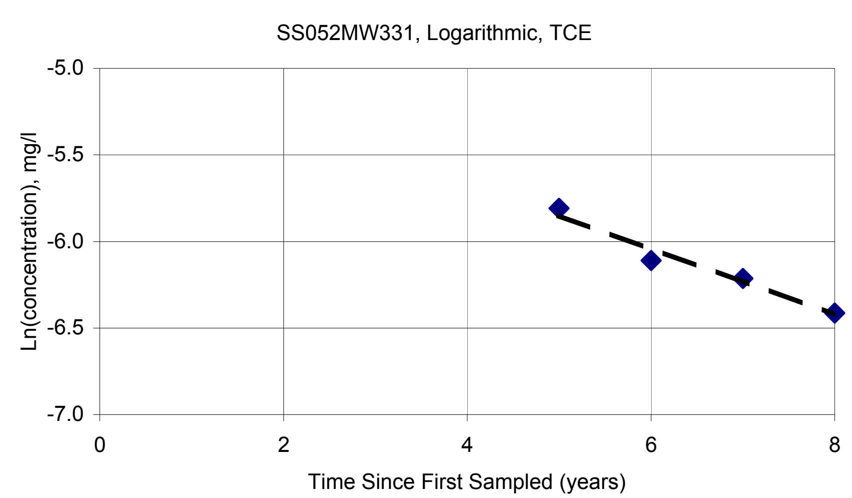
½ Detection Limit or ½ 'U' qualified value

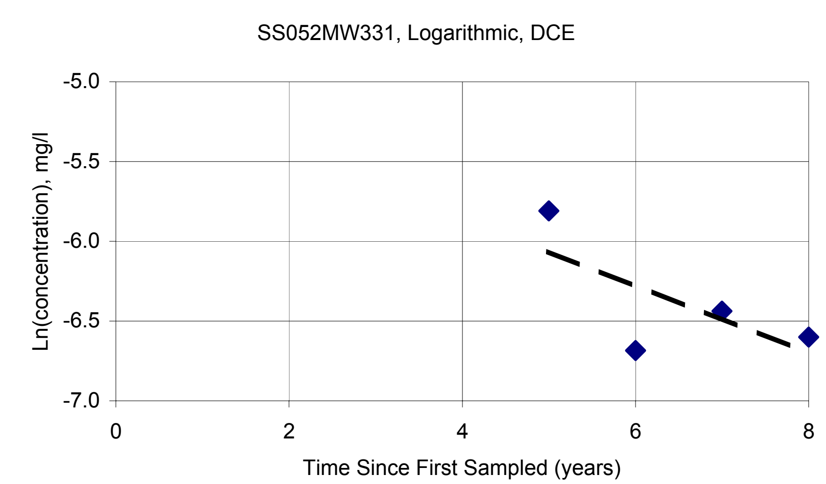












Regression and Mann-Kendall analyses use data shown as solid symbols.

Figure B-8a
Concentration Versus Time Trends for Well SS052MW331 in the SS051 Plume
Zone 4 CMS, Kelly AFB, TX

SS052MW331	Event 1	Event 2	Event 3	Event 4	Sum of
PCE Concentration (mg/l)	**0.003**	**0.00312**	**0.0024**	**0.0022**	Rows
Comparison to Event 1		1	-1	-1	-1
Comparison to Event 2			-1	-1	-2
Comparison to Event 3				-1	-1
				Mann-Kendall Statistic (S)	**-4**
				Trend Present (≥90% Confidence)	**No**

SS052MW331	Event 1	Event 2	Event 3	Event 4	Sum of
TCE Concentration (mg/l)	**0.003**	**0.00222**	**0.002**	**0.00164**	Rows
Comparison to Event 1		-1	-1	-1	-3
Comparison to Event 2			-1	-1	-2
Comparison to Event 3				-1	-1
				Mann-Kendall Statistic (S)	**-6**
				Trend Present (≥90% Confidence)	**Yes**

SS052MW331	Event 1	Event 2	Event 3	Event 4	Sum of
DCE Concentration (mg/l)	**0.003**	**0.00125**	**0.0016**	**0.00136**	Rows
Comparison to Event 1		-1	-1	-1	-3
Comparison to Event 2			1	1	2
Comparison to Event 3				-1	-1
				Mann-Kendall Statistic (S)	**-2**
				Trend Present (≥90% Confidence)	**No**

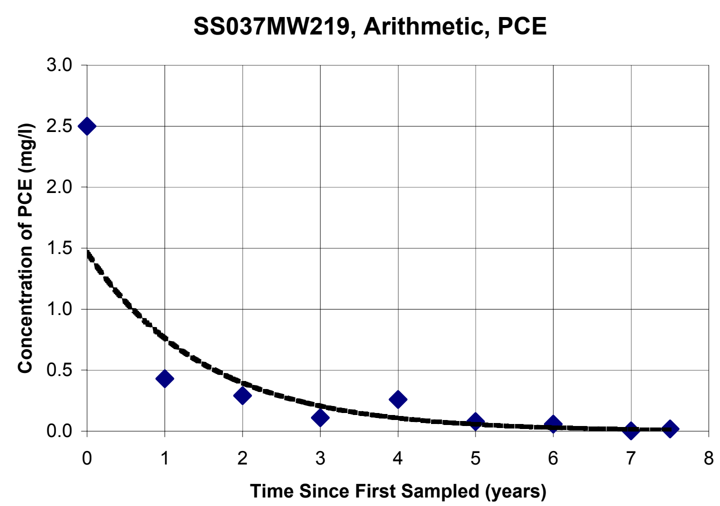
S<0 Deminishing Concentration Trend
S>0 Expanding Concentration Trend

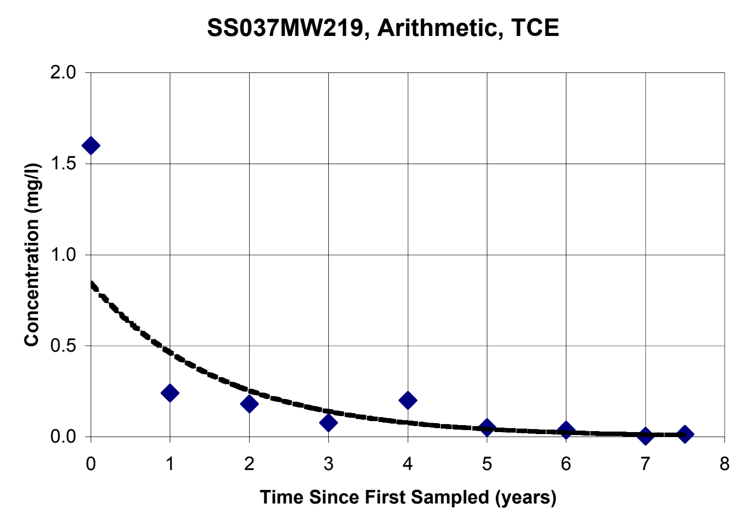
0.016 data used in trend analyses

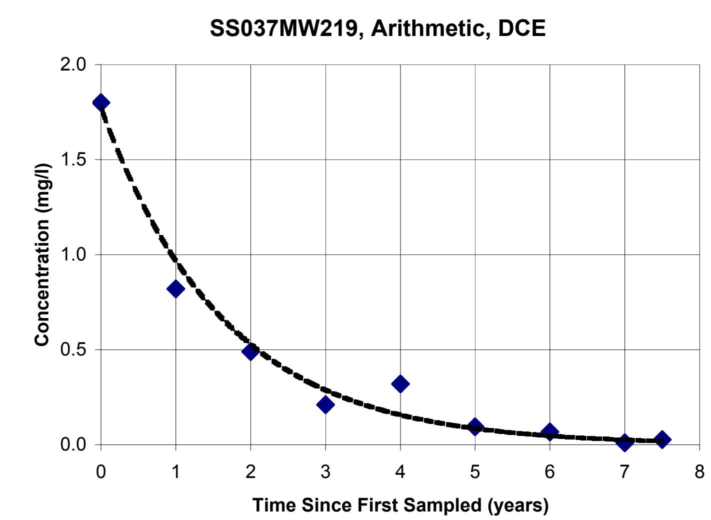
Figure B-8b
Mann-Kendall Analyses for Well SS052MW331 in the SS051 Plume
Zone 4 CMS, Kelly AFB, TX

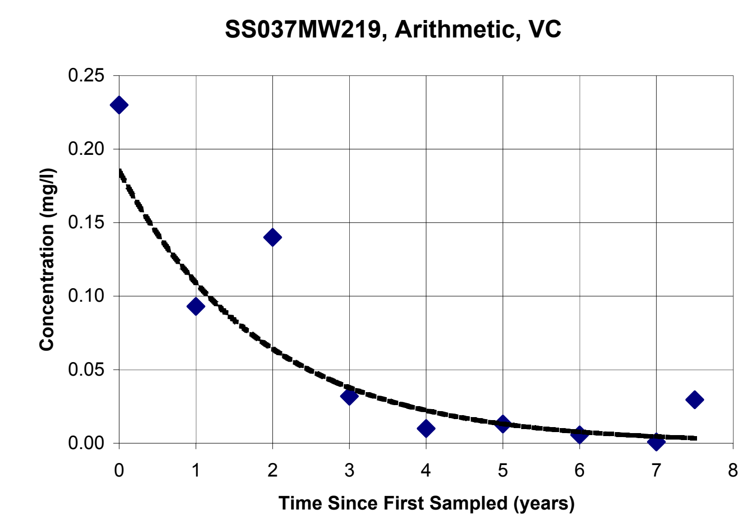
SS037MW219	Years Since First Sampled	PCE	TCE	DCE	VC		Ln of Sample Concentrations PCE	TCE	DCE	VC
1994	0	2.5	1.6	1.8	0.23		0.916	0.470	0.588	-1.470
1995	1	0.43	0.24	0.82	0.093		-0.844	-1.427	-0.198	-2.375
1996	2	0.29	0.18	0.49	0.14		-1.238	-1.715	-0.713	-1.966
1997	3	0.11	0.078	0.21	0.032		-2.207	-2.551	-1.561	-3.442
1998	4	0.26	0.2	0.32	0.01		-1.347	-1.609	-1.139	-4.605
1999	5	0.078	0.051	0.094	0.013		-2.551	-2.976	-2.364	-4.343
2000	6	0.057	0.0377	0.068	0.00573		-2.865	-3.278	-2.688	-5.162
2001	7	0.0039	0.0041	0.0097	0.00084		-5.547	-5.497	-4.636	-7.082
2001	7.5	0.0171	0.0148	0.0263	0.0295		-4.069	-4.213	-3.638	-3.523

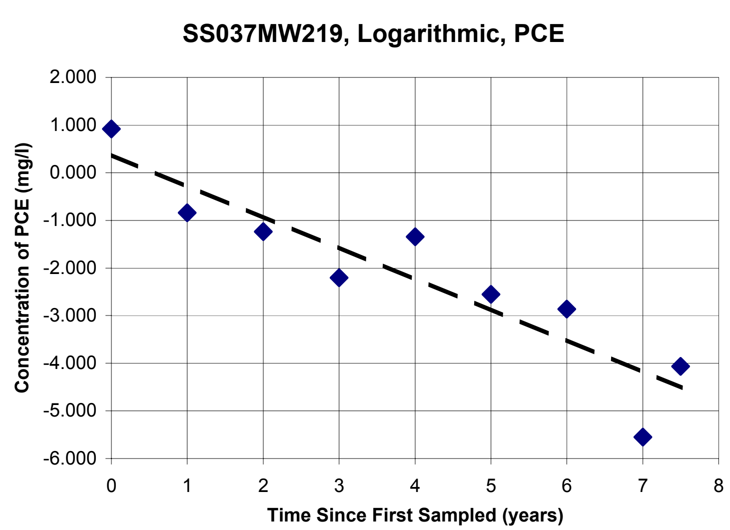
½ Detection Limit or ½ 'U' qualified value

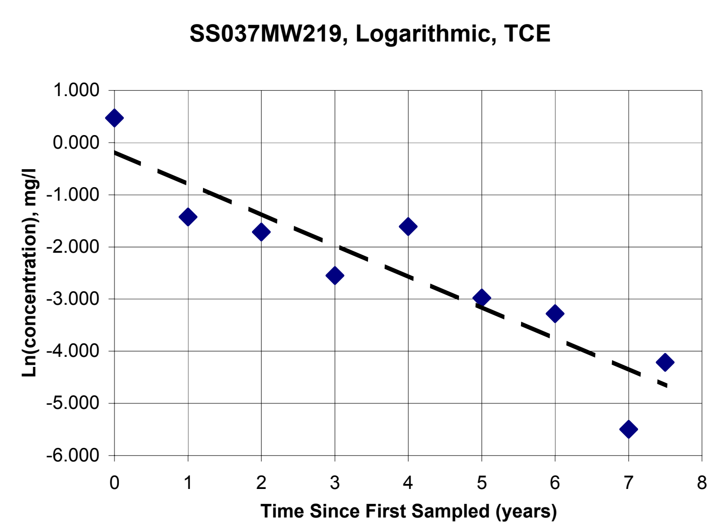


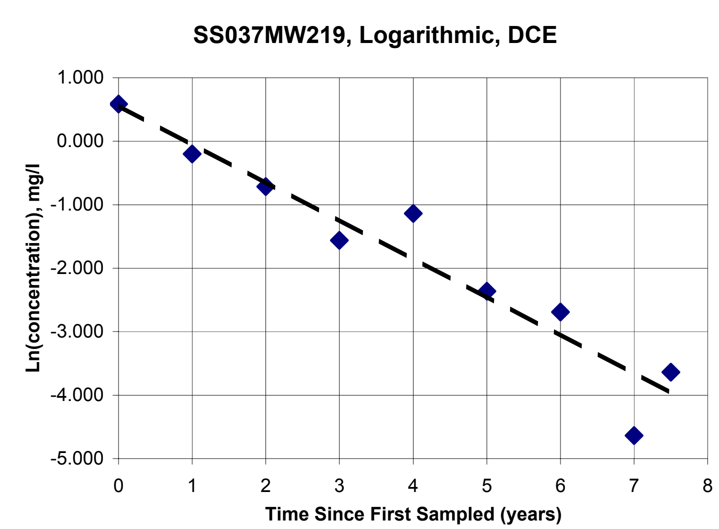


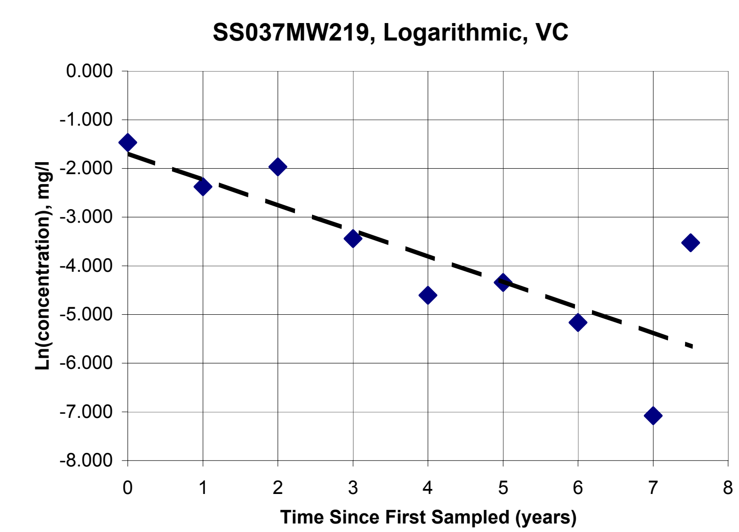












Regression and Mann-Kendall analyses use data shown as solid symbols.

Figure B-9a
Concentration Versus Time Trends for Well SS037MW219 in the MP Plume
Zone 4 CMS, Kelly AFB, TX

SS037MW219	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8	Event 9	Sum of Rows
PCE Concentration (mg/l)	**2.5**	**0.43**	**0.29**	**0.11**	**0.26**	**0.078**	**0.057**	**0.0039**	**0.0171**	
Comparison to Event 1		-1	-1	-1	-1	-1	-1	-1	-1	-8
Comparison to Event 2			-1	-1	-1	-1	-1	-1	-1	-7
Comparison to Event 3				-1	-1	-1	-1	-1	-1	-6
Comparison to Event 4					1	-1	-1	-1	-1	-3
Comparison to Event 5						-1	-1	-1	-1	-4
Comparison to Event 6							-1	-1	-1	-3
Comparison to Event 7								-1	-1	-2
Comparison to Event 8									1	1
									Mann-Kendall Statistic (S)	**-32**
									Trend Present (≥90% Confidence)	**Yes**

SS037MW219	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8	Event 9	Sum of Rows
TCE Concentration (mg/l)	**1.6**	**0.24**	**0.18**	**0.078**	**0.2**	**0.051**	**0.0377**	**0.0041**	**0.0148**	
Comparison to Event 1		-1	-1	-1	-1	-1	-1	-1	-1	-8
Comparison to Event 2			-1	-1	-1	-1	-1	-1	-1	-7
Comparison to Event 3				-1	1	-1	-1	-1	-1	-4
Comparison to Event 4					1	-1	-1	-1	-1	-3
Comparison to Event 5						-1	-1	-1	-1	-4
Comparison to Event 6							-1	-1	-1	-3
Comparison to Event 7								-1	-1	-2
Comparison to Event 8									1	1
									Mann-Kendall Statistic (S)	**-30**
									Trend Present (≥90% Confidence)	**Yes**

SS037MW219	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8	Event 9	Sum of Rows
DCE Concentration (mg/l)	**1.8**	**0.82**	**0.49**	**0.21**	**0.32**	**0.094**	**0.068**	**0.0097**	**0.0263**	
Comparison to Event 1		-1	-1	-1	-1	-1	-1	-1	-1	-8
Comparison to Event 2			-1	-1	-1	-1	-1	-1	-1	-7
Comparison to Event 3				-1	-1	-1	-1	-1	-1	-6
Comparison to Event 4					1	-1	-1	-1	-1	-3
Comparison to Event 5						-1	-1	-1	-1	-4
Comparison to Event 6							-1	1	1	1
Comparison to Event 7								-1	-1	-2
Comparison to Event 8									1	1
									Mann-Kendall Statistic (S)	**-28**
									Trend Present (≥90% Confidence)	**Yes**

SS037MW219	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Event 8	Event 9	Sum of Rows
VC Concentration (mg/l)	**0.23**	**0.093**	**0.14**	**0.032**	**0.01**	**0.013**	**0.0057**	**0.0008**	**0.0295**	
Comparison to Event 1		-1	-1	-1	-1	-1	-1	-1	1	-6
Comparison to Event 2			1	-1	-1	-1	-1	-1	-1	-5
Comparison to Event 3				-1	-1	-1	-1	-1	-1	-6
Comparison to Event 4					-1	-1	-1	-1	-1	-5
Comparison to Event 5						1	-1	-1	1	0
Comparison to Event 6							-1	-1	1	-1
Comparison to Event 7								-1	1	0
Comparison to Event 8									1	1
									Mann-Kendall Statistic (S)	**-22**
									Trend Present (≥90% Confidence)	**Yes**

S<0 Deminishing Concentration Trend

S>0 Expanding Concentration Trend

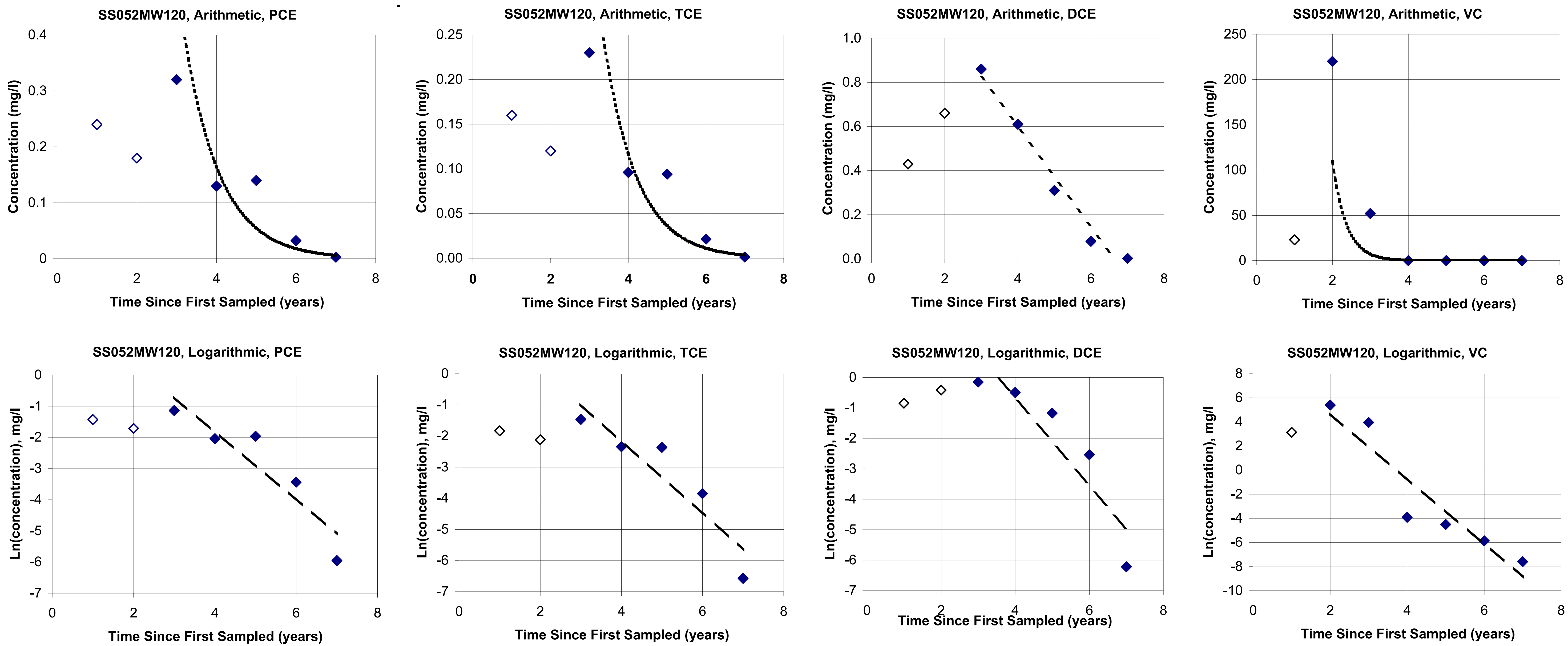
Figure B-9b
Mann-Kendall Analyses for Well SS037MW219 in the MP Plume
Zone 4 CMS, Kelly AFB, TX

SS052MW120

	Years Since First	PCE	TCE	DCE	VC
1994	0				
1995	1	0.24	0.16	0.43	23
1996	2	0.18	0.12	0.66	220
1997	3	0.32	0.23	0.86	52
1998	4	0.13	0.096	0.61	0.02
1999	5	0.14	0.094	0.31	0.011
2000	6	0.0322	0.0213	0.0793	0.00284
2001	7	0.0026	0.0014	0.002	0.0005

Ln of Sample Concentrations			
PCE	TCE	DCE	VC
-1.427	-1.833	-0.844	3.135
-1.715	-2.120	-0.416	5.394
-1.139	-1.470	-0.151	3.951
-2.040	-2.343	-0.494	-3.912
-1.966	-2.364	-1.171	-4.510
-3.436	-3.849	-2.535	-5.864
-5.952	-6.571	-6.215	-7.601

½ Detection Limit or ½ 'U' qualified value



Regression and Mann-Kendall analyses use data shown as solid symbols.

Figure B-10a
Concentration Versus Time Trends for Well SS052MW120 in the MP Plume
Zone 4 CMS, Kelly AFB, TX

SS052MW120	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
PCE Concentration (mg/l)	0.24	0.18	**0.32**	**0.13**	**0.14**	**0.0322**	**0.0026**	
Comparison to Event 1								
Comparison to Event 2								
Comparison to Event 3				-1	-1	-1	-1	-4
Comparison to Event 4					1	-1	-1	-1
Comparison to Event 5						-1	-1	-2
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-8**
							Trend Present (≥90% Confidence)	**Yes**

SS052MW120	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
TCE Concentration (mg/l)	0.16	0.12	**0.23**	**0.096**	**0.094**	**0.0213**	**0.0014**	
Comparison to Event 1								
Comparison to Event 2								
Comparison to Event 3				-1	-1	-1	-1	-4
Comparison to Event 4					-1	-1	-1	-3
Comparison to Event 5						-1	-1	-2
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-10**
							Trend Present (≥90% Confidence)	**Yes**

SS052MW120	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
DCE Concentration (mg/l)	0.43	0.66	**0.86**	**0.61**	**0.31**	**0.0793**	**0.002**	
Comparison to Event 1								
Comparison to Event 2								
Comparison to Event 3				-1	-1	-1	-1	-4
Comparison to Event 4					-1	-1	-1	-3
Comparison to Event 5						-1	-1	-2
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-10**
							Trend Present (≥90% Confidence)	**Yes**

SS052MW120	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
VC Concentration (mg/l)	0.023	**0.22**	**0.052**	**0.02**	**0.011**	**0.0028**	**0.0005**	
Comparison to Event 1								
Comparison to Event 2			-1	-1	-1	-1	-1	-5
Comparison to Event 3				-1	-1	-1	-1	-4
Comparison to Event 4					-1	-1	-1	-3
Comparison to Event 5						-1	-1	-2
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-15**
							Trend Present (≥90% Confidence)	**Yes**

S<0 Deminishing Concentration Trend
S>0 Expanding Concentration Trend

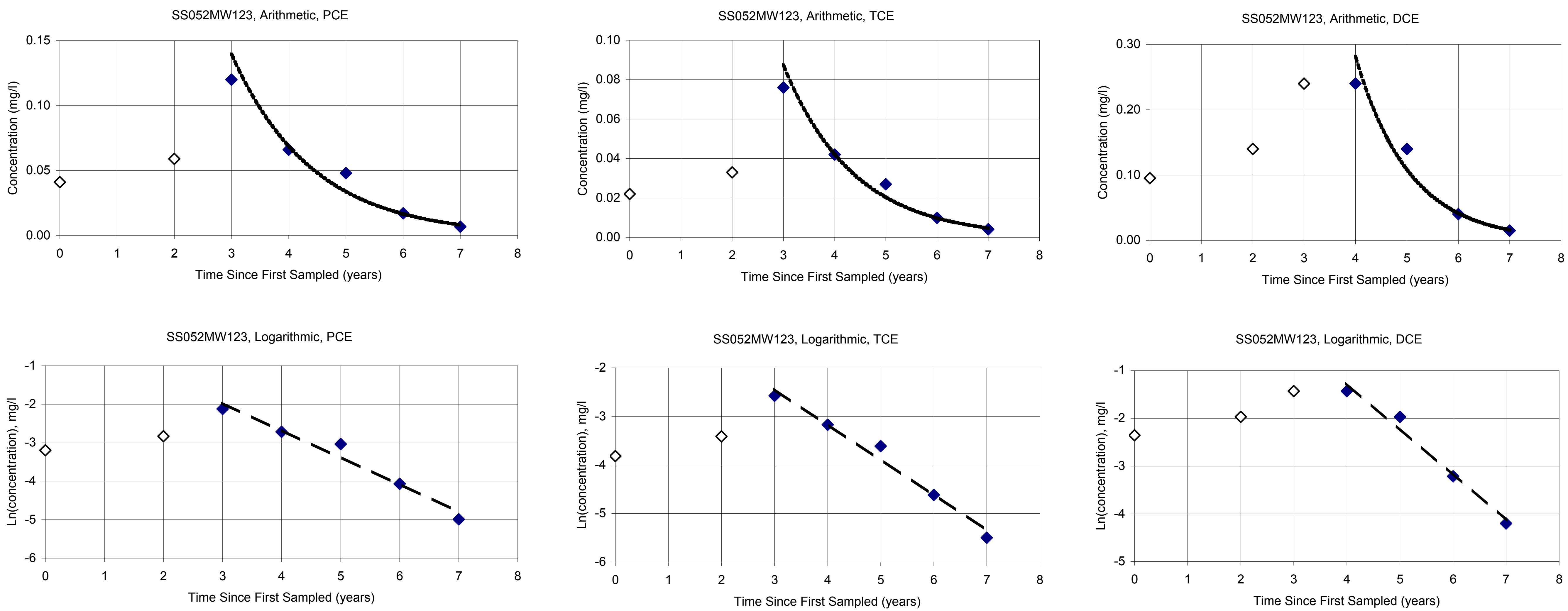
0.22 data used in trend analyses

Figure B-10b
Mann-Kendall Analyses for Well SS052MW120 in the MP Plume
Zone 4 CMS, Kelly AFB, TX

SS052MW123

	Years Since First Sampled	PCE	TCE	DCE	VC	Ln of Sample Concentrations PCE	TCE	DCE	VC
1994	0	0.041	0.022	0.095	0.005	-3.194	-3.817	-2.354	-5.298
1995	1								
1996	2	0.059	0.033	0.14	0.005	-2.830	-3.411	-1.966	-5.298
1997	3	0.12	0.076	0.24	0.005	-2.120	-2.577	-1.427	-5.298
1998	4	0.066	0.042	0.24	0.006	-2.718	-3.170	-1.427	-5.116
1999	5	0.048	0.027	0.14	0.0005	-3.037	-3.612	-1.966	-7.601
2000	6	0.0171	0.00988	0.0402	0.0005	-4.069	-4.617	-3.214	-7.601
2001	7	0.0068	0.0041	0.015	0.0005	-4.991	-5.497	-4.200	-7.601

½ Detection Limit or ½ 'U' qualified value



Regression and Mann-Kendall analyses use data shown as solid symbols.

Figure B-11a
Concentration Versus Time Trends for Well SS052MW123 in the MP Plume
Zone 4 CMS, Kelly AFB, TX

SS052MW123	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
PCE Concentration (mg/l)	0.041	0.059	**0.12**	**0.066**	**0.048**	**0.0171**	**0.0068**	
Comparison to Event 1								
Comparison to Event 2								
Comparison to Event 3				-1	-1	-1	-1	-4
Comparison to Event 4					-1	-1	-1	-3
Comparison to Event 5						-1	-1	-2
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-10**
							Trend Present (≥90% Confidence)	**Yes**

SS052MW123	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
TCE Concentration (mg/l)	0.022	0.033	**0.076**	**0.042**	**0.027**	**0.0099**	**0.0041**	
Comparison to Event 1								
Comparison to Event 2								
Comparison to Event 3				-1	-1	-1	-1	-4
Comparison to Event 4					-1	-1	-1	-3
Comparison to Event 5						-1	-1	-2
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-10**
							Trend Present (≥90% Confidence)	**Yes**

SS052MW123	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 7	Sum of Rows
DCE Concentration (mg/l)	0.095	0.14	0.24	**0.24**	**0.14**	**0.0402**	**0.015**	
Comparison to Event 1								
Comparison to Event 2								
Comparison to Event 3								
Comparison to Event 4					-1	-1	-1	-3
Comparison to Event 5						-1	-1	-2
Comparison to Event 6							-1	-1
							Mann-Kendall Statistic (S)	**-6**
							Trend Present (≥90% Confidence)	**Yes**

S<0 Deminishing Concentration Trend
S>0 Expanding Concentration Trend

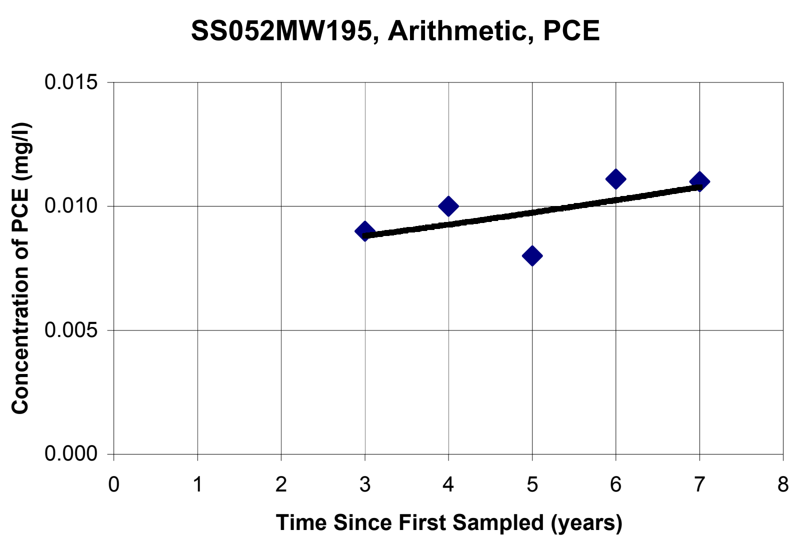
0.24 data used in trend analysis

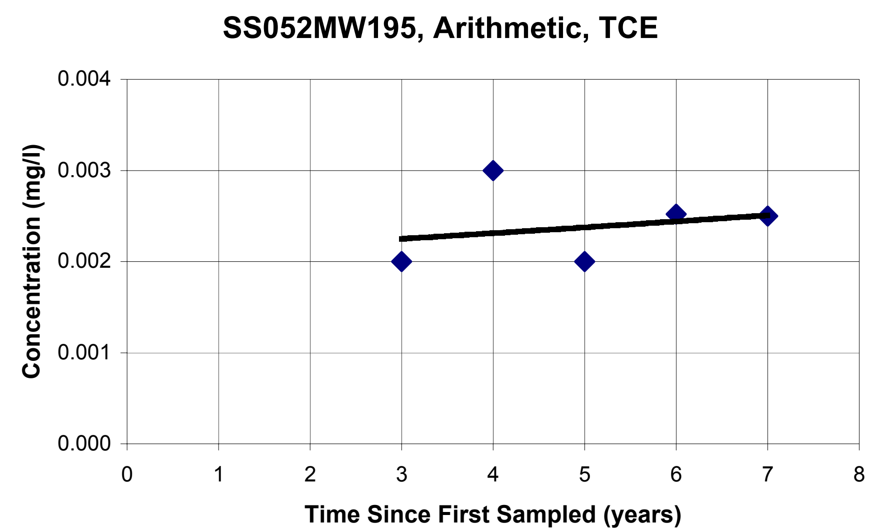
Figure B-11b
Mann-Kendall Analyses for Well SS052MW123 in the MP Plume
Zone 4 CMS, Kelly AFB, TX

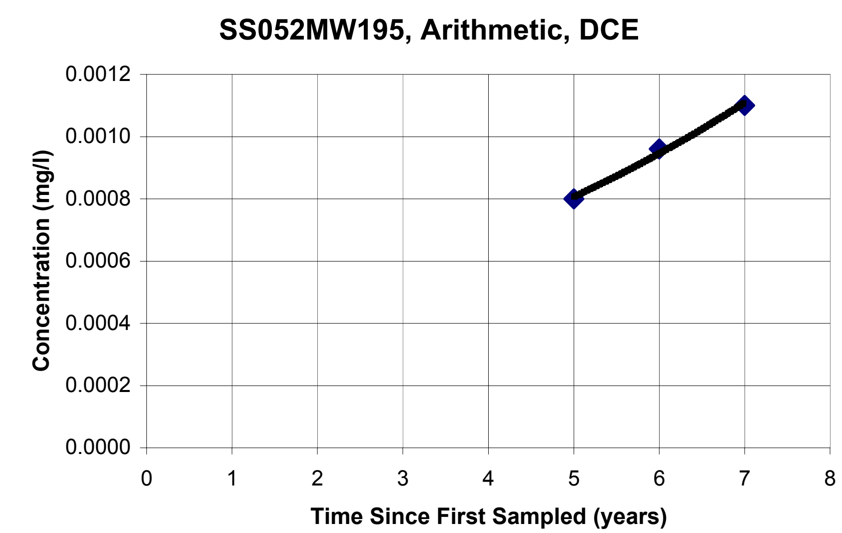
SS052MW195	Years Since First Sampled	PCE	TCE	DCE	VC
1994	0				
1995	1				
1996	2				
1997	3	0.009	0.002		
1998	4	0.01	0.003		
1999	5	0.008	0.002	0.0008	
2000	6	0.0111	0.00252	0.00096	
2001	7	0.011	0.0025	0.0011	

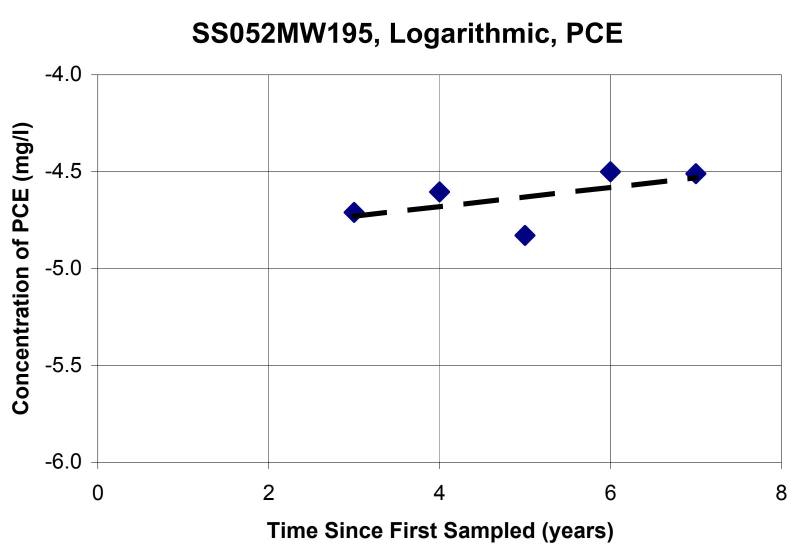
Natural Logs of Concentrations

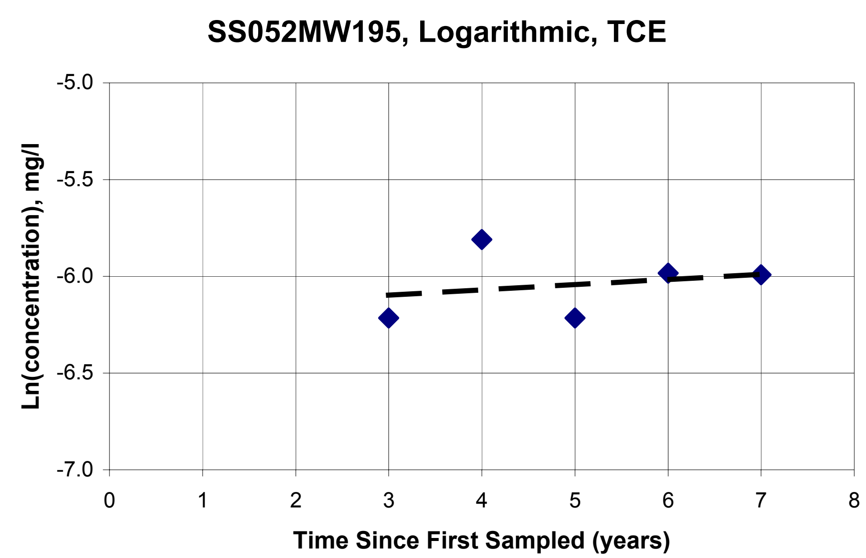
PCE	TCE	DCE	VC
-4.711	-6.215		
-4.605	-5.809		
-4.828	-6.215	-7.131	
-4.501	-5.983	-6.949	
-4.510	-5.991	-6.812	











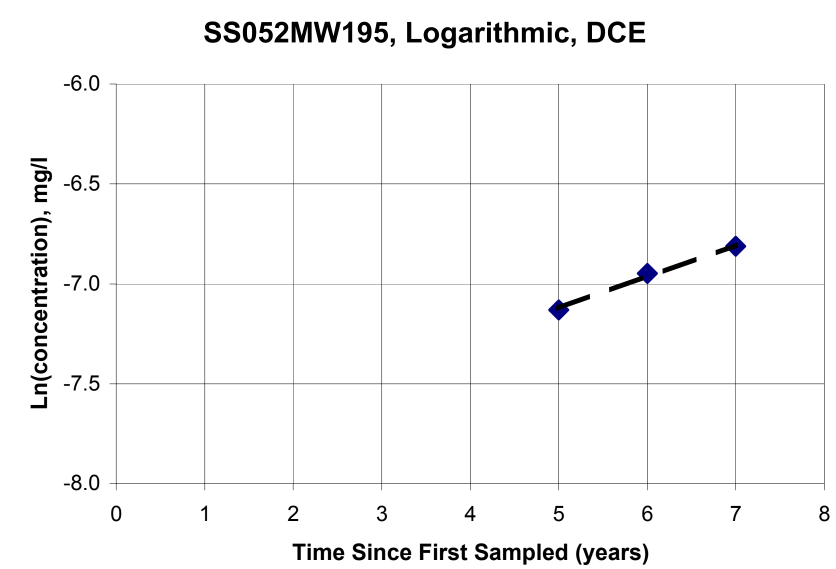


Figure B-12
Concentration Versus Time Trends for Well SS052MW195
Zone 4 CMS, Kelly AFB, TX

SS052MW197	Years Since First Sampled	PCE	TCE	DCE	VC
1994	0				
1995	1				
1996	2				
1997	3	0.032	0.005		
1998	4	0.018	0.005	0.001	
1999	5	0.012	0.003	0.001	
2000	6	0.0155	0.00562	0.00223	
2001	7	0.065	0.0076	0.0037	

Natural Logs of Concentrations

PCE	TCE	DCE	VC
-3.442	-5.298		
-4.017	-5.298	-6.908	
-4.423	-5.809	-6.908	
-4.167	-5.181	-6.106	
-2.733	-4.880	-5.599	

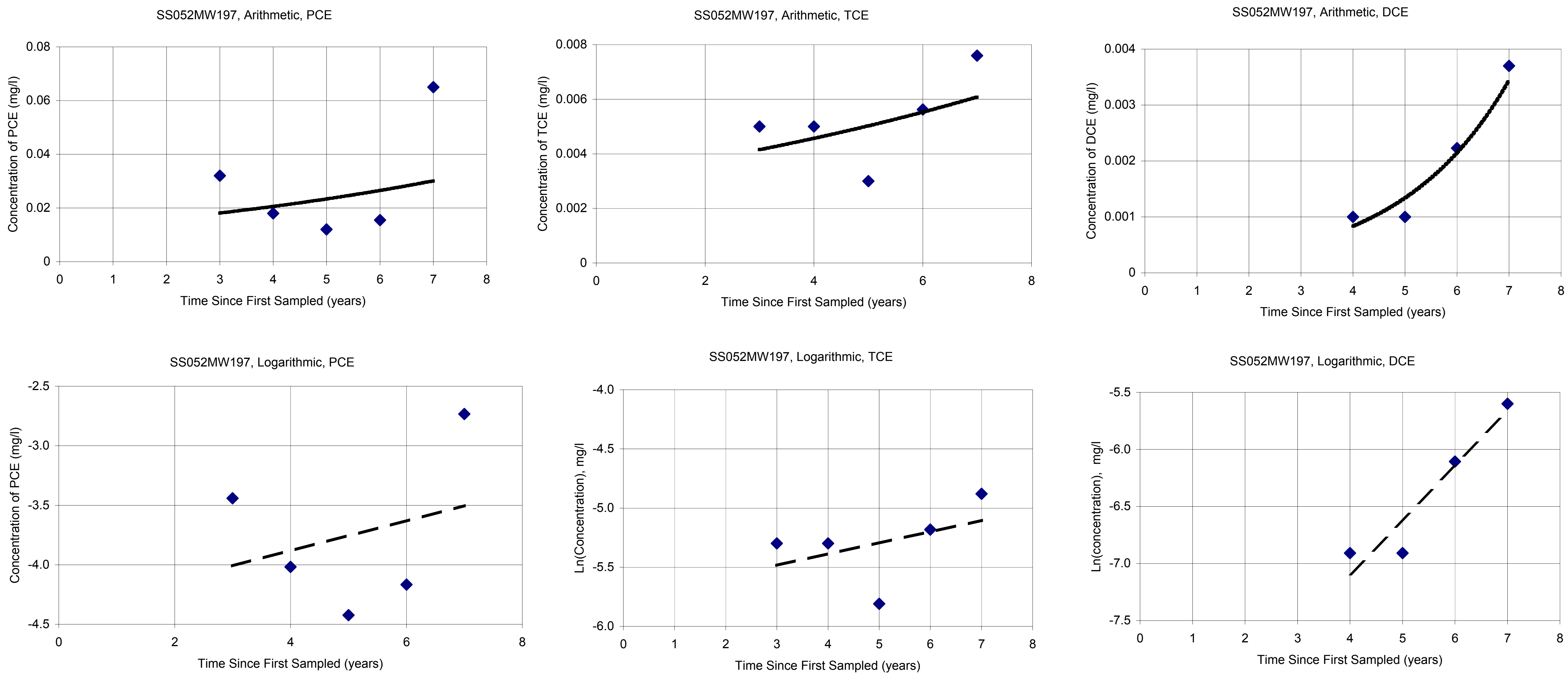


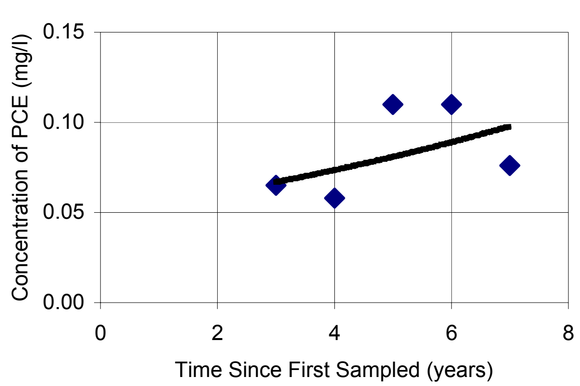
Figure B-13
Concentration Versus Time Trends for Well SS052MW197
Zone 4 CMS, Kelly AFB, TX

SS052MW198	Years Since First Sampled	PCE	TCE	DCE	VC
1994	0				
1995	1				
1996	2				
1997	3	0.065	0.009	0.027	
1998	4	0.058	0.009	0.034	
1999	5	0.11	0.019	0.044	0.002
2000	6	0.11	0.0247	0.0503	0.00129
2001	7	0.076	0.022	0.042	0.0021

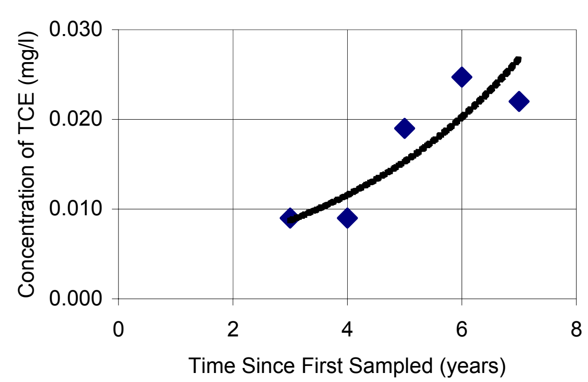
Natural Logs of Concentrations

PCE	TCE	DCE	VC
-2.733	-4.711	-3.612	
-2.847	-4.711	-3.381	
-2.207	-3.963	-3.124	-6.215
-2.207	-3.701	-2.990	-6.653
-2.577	-3.817	-3.170	-6.166

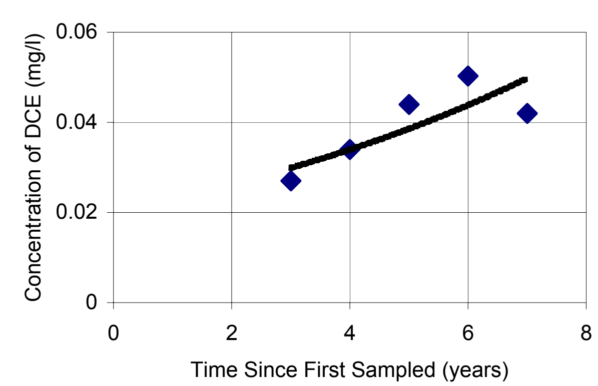
SS052MW198, Arithmetic, PCE



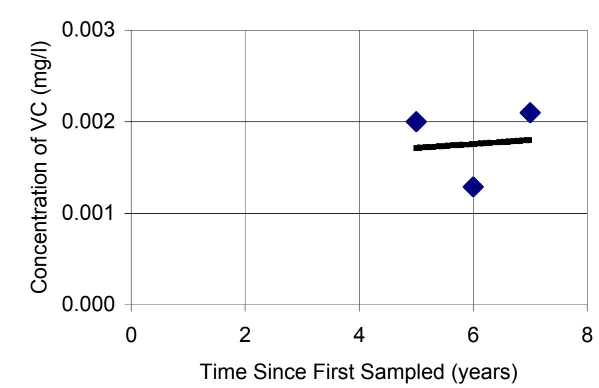
SS052MW198, Arithmetic, TCE



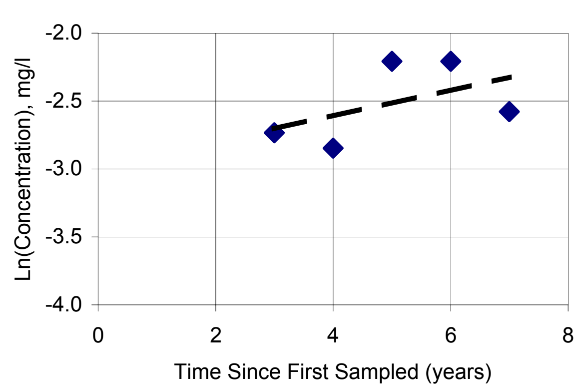
SS052MW198, Arithmetic, DCE



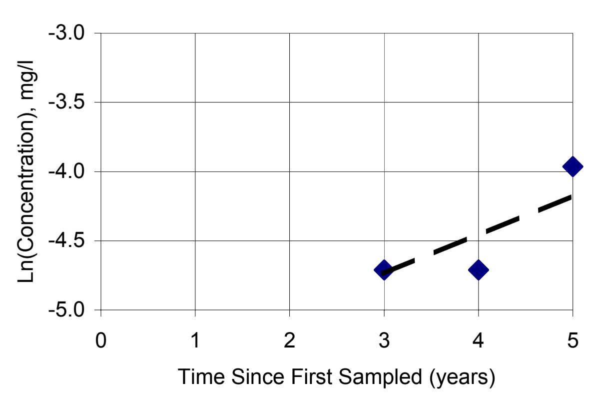
SS052MW198, Arithmetic, VC



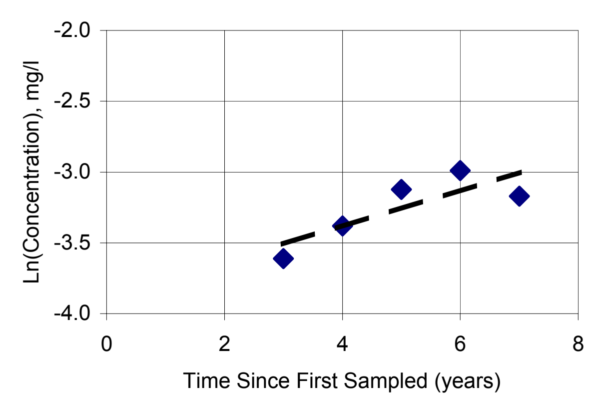
SS052MW198, Logarithmic, PCE



SS052MW198, Logarithmic, TCE



SS052MW198, Logarithmic, DCE



SS052MW198, Logarithmic, VC

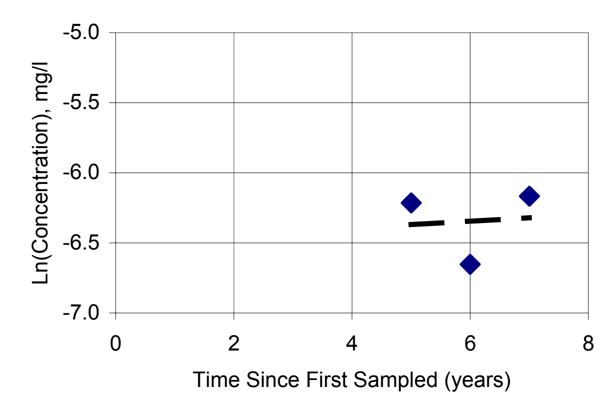


Figure B-14
Concentration Versus Time Trends for Well SS052MW198
Zone 4 CMS, Kelly AFB, TX

APPENDIX C

Cost of Remedial Solutions

COMPARISON OF TOTAL COST OF REMEDIAL SOLUTIONS

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study

Base Year: 2000
Date: 4/16/02 14:27

	Alternative A	**Alternative A1**	**Alternative B**	**Alternaive C**	**Alternaive C1**	**Alternative D**	**Alternative E**	**Alternative E1**	**Alternative F**	**Alternative G**	**Alternative H**	**Alternative I**	**Pref. Alternative**
	Pump and Treat Plume-Wide with a River Trench	Pump and Treat Plume-Wide Down Plume Centerlines with a River Trench	Limited Pump and Treat, Phytoremediation at the River, and MNA	Pump and Treat Plume-Wide with Re-Injection of Treated GW and River Trench	Pump & Treat Plume-Wide Down Plume Centerlines, Re-Inject Treated GW, and River Trench	Existing Source Controls and MNA	Flow-Through Reactive Walls Plume-Wide and Along River	Flow-Through Reactive Walls Plume-Wide Down Plume Centerlines and Along the River	Limited Flow-Through Reactive Walls and MNA	Limited Microorganism Breakdown and MNA	Limited Oxygen Treatment and MNA	Limited Air Injection/Vapor Removal and MNA	Limited PRBs, Pump and Treat and MNA
Total Project Duration (Years)	15	15	18	15	15	22	18	18	18	18	18	18	16
Capital Cost	$74,490,000	$8,900,000	$2,800,000	$129,240,000	$14,680,000	$90,000	$21,690,000	$28,170,000	$8,870,000	$25,670,000	$37,450,000	$25,140,000	$14,320,000
Annual O&M Cost	$13,140,000	$1,570,000	$900,000	$17,350,000	$2,010,000	$330,000	$360,000	$430,000	$420,000	$4,880,000	$3,370,000	$8,230,000	$4,534,391
Total Periodic Cost	---	---	$163,000	---	---	$163,000	---	---	$163,000	$163,000	$163,000	$163,000	$552,115
Total Present Value of Solution	$194,170,000	$23,200,000	$12,410,000	$287,260,000	$32,990,000	$4,290,000	$25,310,000	$32,500,000	$13,650,000	$75,310,000	$71,900,000	$108,480,000	$19,406,506

Disclaimer: The information in this cost estimate is based on the best available information regarding the anticipated scope of the remedial alternatives. Changes in the cost elements are likely to occur as a result of new information and data collected during the engineering design of the remedial alternatives. This is an order-of-magnitude cost estimate that is expected to be within -50 to +100 percent of the actual project costs.

Alternative: **Alternative A**

COST ESTIMATE SUMMARY

Name: **Pump and Treat Plume-Wide with a River Trench**

Site: Kelly Air Force Base, Texas

Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Installation of horizontal extraction wells every 1,000 feet, a recovery trench along the San Antonio River, and construction of utraviolet/oxidation (UV/Ox) treatment systems to treat extracted groundwater to Corrective Action Objectives standards. Treated groundwater would be discharged to a sewer system or a surface water body. GW monitoring for VOCs.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Horizontal Extraction Wells	180	EA	$208,000	$37,440,000	See Cost Worksheet 1
River Trench	1	EA	$661,000	$661,000	See Cost Worksheet 2
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
Groundwater Treatment System (UV/Ox)	45	EA	$284,000	$12,780,000	See Cost Worksheet 4
SUBTOTAL				$50,931,000	
Contingency	25%		$50,931,000	$12,732,750	10% Scope + 15% Bid
SUBTOTAL				$63,663,750	
Project Management	5%		$63,663,750	$3,183,188	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$63,663,750	$3,819,825	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$63,663,750	$3,819,825	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$10,822,838	
TOTAL CAPITAL COST				**$74,490,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Horizontal Extraction/Injection Wells	180	EA	$18,000	$3,240,000	See Cost Worksheet 1
River Trench	1	EA	$15,000	$15,000	See Cost Worksheet 2
Annual Groundwater Monitoring	50	MWs	$2,000	$100,000	See Cost Worksheet 5
Groundwater Treatment System (UV/Ox)	45	EA	$150,000	$6,750,000	See Cost Worksheet 4
SUBTOTAL				$10,105,000	
Contingency	30%		$10,105,000	$3,031,500	10% Scope + 20% Bid
SUBTOTAL				$13,136,500	
TOTAL ANNUAL O&M COST				**$13,140,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$74,490,000	$74,490,000	1.000	$74,490,000	
15	ANNUAL O&M COST	$197,100,000	$13,140,000	9.108	$119,677,990	15 year O&M period
		$271,590,000			$194,167,990	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$194,170,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative A1** **COST ESTIMATE SUMMARY**

Name: **Pump and Treat Plume-Wide Down Plume Centerlines with a River Trench**

Site: Kelly Air Force Base, Texas

Location: Zone 4 Shallow Groundwater

Phase: Corrective Measures Study

Base Year: 2000

Date: 4/16/02 14:27

Description: Installation of horizontal extraction wells along plume centerlines a recovery trench along the San Antonio River, and construction of utraviolet/oxidation (UV/Ox) treatment systems to treat extracted groundwater to Corrective Action Objective standards. Treated groundwater would be discharged to a sewer system or a surface water body. GW monitoring for VOCs

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Horizontal Extraction Wells	19	EA	$208,000	$3,952,000	See Cost Worksheet 1
River Trench	1	EA	$661,000	$661,000	See Cost Worksheet 2
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
Groundwater Treatment System (UV/Ox)	5	EA	$284,000	$1,420,000	See Cost Worksheet 4
SUBTOTAL				$6,083,000	
Contingency	25%		$6,083,000	$1,520,750	10% Scope + 15% Bid
SUBTOTAL				$7,603,750	
Project Management	5%		$7,603,750	$380,188	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$7,603,750	$456,225	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$7,603,750	$456,225	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$1,292,638	
TOTAL CAPITAL COST				**$8,900,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Horizontal Extraction/Injection Wells	19	EA	$18,000	$342,000	See Cost Worksheet 1
River Trench	1	EA	$15,000	$15,000	See Cost Worksheet 2
Annual Groundwater Monitoring	50	MWs	$2,000	$100,000	See Cost Worksheet 5
Groundwater Treatment System (UV/Ox)	5	EA	$150,000	$750,000	See Cost Worksheet 4
SUBTOTAL				$1,207,000	
Contingency	30%		$1,207,000	$362,100	10% Scope + 20% Bid
SUBTOTAL				$1,569,100	
TOTAL ANNUAL O&M COST				**$1,570,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$8,900,000	$8,900,000	1.000	$8,900,000	
15	ANNUAL O&M COST	$23,550,000	$1,570,000	9.108	$14,299,425	15 year O&M period
		$32,450,000			$23,199,425	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$23,200,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative B** **COST ESTIMATE SUMMARY**

Name: **Limited Pump and Treat, Phytoremediation at the River, and MNA**

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Installation of horizontal extraction wells in areas >100 ppb, and construction of utraviolet/oxidation (UV/Ox) treatment systems to treat extracted groundwater to Corrective Action Objective standards. Phytoremediation would be implemented along the San Antonio River. Monitored natural attenuation would be implemented throughout the contaminated area.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Horizontal Extraction Wells	6	EA	$208,000	$1,248,000	See Cost Worksheet 1
Phytoremediation	1	LS	$50,000	$50,000	See Cost Worksheet 6
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
Groundwater Treatment System (UV/Ox)	2	EA	$284,000	$568,000	See Cost Worksheet 4
SUBTOTAL				$1,916,000	
Contingency	25%		$1,916,000	$479,000	10% Scope + 15% Bid
SUBTOTAL				$2,395,000	
Project Management	5%		$2,395,000	$119,750	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$2,395,000	$143,700	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$2,395,000	$143,700	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$407,150	
TOTAL CAPITAL COST				**$2,800,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Horizontal Extraction Wells	6	EA	$18,000	$108,000	See Cost Worksheet 1
Phytoremediation O&M	1	EA	$38,000	$38,000	See Cost Worksheet 6
Annual Groundwater Monitoring	125	MWs	$2,000	$250,000	See Cost Worksheet 5
Groundwater Treatment System (UV/Ox)	2	EA	$150,000	$300,000	See Cost Worksheet 4
SUBTOTAL				$696,000	
Contingency	30%		$696,000	$208,800	10% Scope + 20% Bid
SUBTOTAL				$904,800	
TOTAL ANNUAL O&M COST				**$900,000**	

PERIODIC COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Monitored Natural Attenuation Sampling	125	MWs	$1,000	$125,000	See Cost Worksheet 5. Assume MNA Sampling during Yrs 1 - 4
Subtotal				$125,000	
Contingency	30%		$125,000	$37,500	10% Scope + 20% Bid
SUBTOTAL				$162,500	
TOTAL ANNUAL PERIODIC COST				**$163,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$2,800,000	$2,800,000	1.000	$2,800,000	
18	ANNUAL O&M COST	$16,200,000	$900,000	10.059	$9,053,178	18 year O&M period
4	PERIODIC COST	$652,000	$163,000	3.387	$552,115	
		$19,652,000			$12,405,294	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$12,410,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternaive C** **COST ESTIMATE SUMMARY**

Name: **Pump and Treat Plume-Wide with Re-Injection of Treated GW and River Trench**

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Installation of horizontal extraction wells throughout the plume, and construction of utraviolet/oxidation (UV/Ox) treatment systems to treat extracted groundwater to Corrective Action Objective standards. Treated groundwater would be re-injected into the ground using horizontal injection wells. Recovery trench along the San Antonio River. GW monitoring for VOCs.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Horizontal Extraction Wells	180	EA	$208,000	$37,440,000	See Cost Worksheet 1
Horizontal Injection Wells	180	EA	$208,000	$37,440,000	See Cost Worksheet 1
River Trench	1	EA	$661,000	$661,000	See Cost Worksheet 2
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
Groundwater Treatment System (UV/Ox)	45	EA	$284,000	$12,780,000	See Cost Worksheet 4
SUBTOTAL				$88,371,000	
Contingency	25%		$88,371,000	$22,092,750	10% Scope + 15% Bid
SUBTOTAL				$110,463,750	
Project Management	5%		$110,463,750	$5,523,188	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$110,463,750	$6,627,825	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$110,463,750	$6,627,825	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$18,778,838	
TOTAL CAPITAL COST				**$129,240,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Horizontal Extraction Wells	180	EA	$18,000	$3,240,000	See Cost Worksheet 1
Horizontal Injection Wells	180	EA	$18,000	$3,240,000	See Cost Worksheet 1
River Trench	1	EA	$15,000	$15,000	See Cost Worksheet 2
Annual Groundwater Monitoring	50	MWs	$2,000	$100,000	See Cost Worksheet 5
Groundwater Treatment System (UV/Ox)	45	EA	$150,000	$6,750,000	See Cost Worksheet 4
SUBTOTAL				$13,345,000	
Contingency	30%		$13,345,000	$4,003,500	10% Scope + 20% Bid
SUBTOTAL				$17,348,500	
TOTAL ANNUAL O&M COST				**$17,350,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$129,240,000	$129,240,000	1.000	$129,240,000	
15	ANNUAL O&M COST	$260,250,000	$17,350,000	9.108	$158,022,308	15 year O&M period
		$389,490,000			$287,262,308	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$287,260,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternaive C1** **COST ESTIMATE SUMMARY**
Name: **Pump & Treat Plume-Wide Down Plume Centerlines, Re-Inject Treated GW, and River Trench**

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Installation of horizontal extraction wells down the centerline, and construction of utraviolet/oxidation (UV/Ox) treatment systems to treat extracted groundwater to Corrective Action Objective standards. Treated groundwater would be re-injected into the ground using horizontal injection wells. A recovery trench would also be placed along the River. GW monitoring for VOCs.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Horizontal Extraction Wells	19	EA	$208,000	$3,952,000	See Cost Worksheet 1
Horizontal Injection Wells	19	EA	$208,000	$3,952,000	See Cost Worksheet 1
Recovery Trench	1	EA	$661,000	$661,000	See Cost Worksheet 2
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
Groundwater Treatment System (UV/Ox)	5	EA	$284,000	$1,420,000	See Cost Worksheet 4
SUBTOTAL				$10,035,000	
Contingency	25%		$10,035,000	$2,508,750	10% Scope + 15% Bid
SUBTOTAL				$12,543,750	
Project Management	5%		$12,543,750	$627,188	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$12,543,750	$752,625	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$12,543,750	$752,625	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$2,132,438	
TOTAL CAPITAL COST				**$14,680,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Horizontal Extraction Wells	19	EA	$18,000	$342,000	See Cost Worksheet 1
Horizontal Injection Wells	19	EA	$18,000	$342,000	See Cost Worksheet 1
River Trench	1	EA	$15,000	$15,000	See Cost Worksheet 2
Annual Groundwater Monitoring	50	MWs	$2,000	$100,000	See Cost Worksheet 5
Groundwater Treatment System (UV/Ox)	5	EA	$150,000	$750,000	See Cost Worksheet 4
SUBTOTAL				$1,549,000	
Contingency	30%		$1,549,000	$464,700	10% Scope + 20% Bid
SUBTOTAL				$2,013,700	
TOTAL ANNUAL O&M COST				**$2,010,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$14,680,000	$14,680,000	1.000	$14,680,000	
15	ANNUAL O&M COST	$30,150,000	$2,010,000	9.108	$18,306,907	15 year O&M period
		$44,830,000			$32,986,907	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$32,990,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative D**

Name: **Existing Source Controls and MNA**

COST ESTIMATE SUMMARY

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Continued use of existing source control systems and monitored natural attenuation implemented throughout the contaminated area.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
SUBTOTAL				$50,000	
Contingency	25%		$50,000	$12,500	10% Scope + 15% Bid
SUBTOTAL				$62,500	
Project Management	10%		$62,500	$6,250	USEPA 2000, p. 5-13, <$100K
Remedial Design	20%		$62,500	$12,500	USEPA 2000, p. 5-13, <$100K
Construction Management	15%		$62,500	$9,375	USEPA 2000, p. 5-13, <$100K
SUBTOTAL				$28,125	
TOTAL CAPITAL COST				**$90,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Annual Groundwater Monitoring	125	MWs	$2,000	$250,000	See Cost Worksheet 5
SUBTOTAL				$250,000	
Contingency	30%		$250,000	$75,000	10% Scope + 20% Bid
SUBTOTAL				$325,000	
TOTAL ANNUAL O&M COST				**$330,000**	

PERIODIC COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Monitored Natural Attenuation Sampling	125	MWs	$1,000	$125,000	See Cost Worksheet 5. Assume MNA Sampling during Yrs 1 - 4
Subtotal				$125,000	
Contingency	30%		$125,000	$37,500	10% Scope + 20% Bid
SUBTOTAL				$162,500	
TOTAL ANNUAL PERIODIC COST				**$163,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$90,000	$90,000	1.000	$90,000	
22	ANNUAL O&M COST	$7,260,000	$330,000	11.061	$3,650,209	22 year O&M period
4	PERIODIC COST	$652,000	$163,000	3.387	$552,115	
		$8,002,000			$4,292,325	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$4,290,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative E** **COST ESTIMATE SUMMARY**

Name: **Flow-Through Reactive Walls Plume-Wide and Along River**

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Installation of permeable reactive barriers plume-wide (9) (i.e., flow through reactive walls) to treat groundwater. A permeable reactive barrier (1) would also be installed along the San Antonio River. GW monitoring for VOCs

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Permeable Reactive Barrier	10	EA	$1,478,000	$14,780,000	See Cost Worksheet 7
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
SUBTOTAL				$14,830,000	
Contingency	25%		$14,830,000	$3,707,500	10% Scope + 15% Bid
SUBTOTAL				$18,537,500	
Project Management	5%		$18,537,500	$926,875	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$18,537,500	$1,112,250	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$18,537,500	$1,112,250	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$3,151,375	
TOTAL CAPITAL COST				**$21,690,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Permeable Reactive Barrier O&M	10	EA	$18,000	$180,000	See Cost Worksheet 7
Annual Groundwater Monitoring	50	MWs	$2,000	$100,000	See Cost Worksheet 5
SUBTOTAL				$280,000	
Contingency	30%		$280,000	$84,000	10% Scope + 20% Bid
SUBTOTAL				$364,000	
TOTAL ANNUAL O&M COST				**$360,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$21,690,000	$21,690,000	1.000	$21,690,000	
18	ANNUAL O&M COST	$6,480,000	$360,000	10.059	$3,621,271	18 year O&M period
		$28,170,000			$25,311,271	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$25,310,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative E1** — **COST ESTIMATE SUMMARY**

Name: **Flow-Through Reactive Walls Plume-Wide Down Plume Centerlines and Along the River**

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Installation of permeable reactive barriers (i.e., flow through reactive walls) to treat groundwater. The permeable reactive barriers would be installed down the centerline of the groundwater plumes (11) and along the San Antonio River (2). GW monitoring for VOCs

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Permeable Reactive Barrier (11 plume + 2 river)	13	EA	$1,478,000	$19,214,000	See Cost Worksheet 7
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
SUBTOTAL				$19,264,000	
Contingency	25%		$19,264,000	$4,816,000	10% Scope + 15% Bid
SUBTOTAL				$24,080,000	
Project Management	5%		$24,080,000	$1,204,000	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$24,080,000	$1,444,800	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$24,080,000	$1,444,800	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$4,093,600	
TOTAL CAPITAL COST				**$28,170,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Permeable Reactive Barrier O&M	13	EA	$18,000	$234,000	See Cost Worksheet 7
Annual Groundwater Monitoring	50	MWs	$2,000	$100,000	See Cost Worksheet 5
SUBTOTAL				$334,000	
Contingency	30%		$334,000	$100,200	10% Scope + 20% Bid
SUBTOTAL				$434,200	
TOTAL ANNUAL O&M COST				**$430,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$28,170,000	$28,170,000	1.000	$28,170,000	
18	ANNUAL O&M COST	$7,740,000	$430,000	10.059	$4,325,407	18 year O&M period
		$35,910,000			$32,495,407	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$32,500,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative F**
Name: **Limited Flow-Through Reactive Walls and MNA**

COST ESTIMATE SUMMARY

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Installation of permeable reactive barriers in areas within the groundwater plume >100 ppb
Monitored natural attenuation would implemented throughout the contaminated area.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Permeable Reactive Barrier	4	EA	$1,478,000	$5,912,000	See Cost Worksheet 7
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
SUBTOTAL				$5,962,000	
Contingency	25%		$5,962,000	$1,490,500	10% Scope + 15% Bid
SUBTOTAL				$7,452,500	
Project Management	5%		$7,452,500	$372,625	USEPA 2000, p. 5-13, $2M-$10M
Remedial Design	8%		$7,452,500	$596,200	USEPA 2000, p. 5-13, $2M-$10M
Construction Management	6%		$7,452,500	$447,150	USEPA 2000, p. 5-13, $2M-$10M
SUBTOTAL				$1,415,975	
TOTAL CAPITAL COST				**$8,870,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Permeable Reactive Barrier O&M	4	EA	$18,000	$72,000	See Cost Worksheet 7
Annual Groundwater Monitoring	125	MWs	$2,000	$250,000	See Cost Worksheet 5
SUBTOTAL				$322,000	
Contingency	30%		$322,000	$96,600	10% Scope + 20% Bid
SUBTOTAL				$418,600	
TOTAL ANNUAL O&M COST				**$420,000**	

PERIODIC COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Monitored Natural Attenuation Sampling	125	MWs	$1,000	$125,000	See Cost Worksheet 5. Assume MNA Sampling during Yrs 1 - 4
Subtotal				$125,000	
Contingency	30%		$125,000	$37,500	10% Scope + 20% Bid
SUBTOTAL				$162,500	
TOTAL ANNUAL PERIODIC COST				**$163,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$8,870,000	$8,870,000	1.000	$8,870,000	
18	ANNUAL O&M COST	$7,560,000	$420,000	10.059	$4,224,817	18 year O&M period
4	PERIODIC COST	$652,000	$163,000	3.387	$552,115	
		$17,082,000			$13,646,932	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$13,650,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative G** **COST ESTIMATE SUMMARY**
Name: **Limited Microorganism Breakdown and MNA**

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Tech Eval of CMAs
Base Year: 2000
Date: 4/16/02 14:27

Description: Performance of enhanced biodegradation to create favorable conditions for naturally occurring micorganisms to degrade contaminants. Anaerobic reductive dehalogenation processes were considered by addition of vegetable oil into the shallow groundwater. Monitored natural attenuation would be implemented throughout the contaminated area.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Microorganism Injection Well System	3,500	WELLS	$5,000	$17,500,000	See Cost Worksheet 8
Monitoring Wells	25	EA	$2,000	$50,000	
SUBTOTAL				$17,550,000	
Contingency	25%		$17,550,000	$4,387,500	10% Scope + 15% Bid
SUBTOTAL				$21,937,500	
Project Management	5%		$21,937,500	$1,096,875	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$21,937,500	$1,316,250	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$21,937,500	$1,316,250	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$3,729,375	
TOTAL CAPITAL COST				**$25,670,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Injection Well O&M	3,500	EA	$1,000	$3,500,000	See Cost Worksheet 8
Annual Groundwater Monitoring	125	MWs	$2,000	$250,000	See Cost Worksheet 5
SUBTOTAL				$3,750,000	
Contingency	30%		$3,750,000	$1,125,000	10% Scope + 20% Bid
SUBTOTAL				$4,875,000	
TOTAL ANNUAL O&M COST				**$4,880,000**	

PERIODIC COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Monitored Natural Attenuation Sampling	125	MWs	$1,000	$125,000	See Cost Worksheet 5. Assume MNA Sampling during Yrs 1 - 4
Subtotal				$125,000	
Contingency	30%		$125,000	$37,500	10% Scope + 20% Bid
SUBTOTAL				$162,500	
TOTAL ANNUAL PERIODIC COST				**$163,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$25,670,000	$25,670,000	1.000	$25,670,000	
18	ANNUAL O&M COST	$87,840,000	$4,880,000	10.059	$49,088,344	18 year O&M period
4	PERIODIC COST	$652,000	$163,000	3.387	$552,115	
		$114,162,000			$75,310,460	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$75,310,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative H** **COST ESTIMATE SUMMARY**

Name: **Limited Oxygen Treatment and Monitored Natural Attenuation**

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Performance of oxygen treatment (in-situ oxidation) using potassium permanganate and monitored natural attenuation throughout the contaminated area.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Horizontal Injection Wells	90	EA	$208,000	$18,720,000	See Cost Worksheet 1
Oxygen Injection System	90	EA	$76,000	$6,840,000	See Cost Worksheet 9
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
SUBTOTAL				$25,610,000	
Contingency	25%		$25,610,000	$6,402,500	10% Scope + 15% Bid
SUBTOTAL				$32,012,500	
Project Management	5%		$32,012,500	$1,600,625	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$32,012,500	$1,920,750	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$32,012,500	$1,920,750	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$5,442,125	
TOTAL CAPITAL COST				**$37,450,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Control Systems O&M					
Horizontal Injection Wells	90	EA	$18,000	$1,620,000	See Cost Worksheet 1
Oxygen Treatment Unit	90	EA	$8,000	$720,000	See Cost Worksheet 9
Annual Groundwater Monitoring	125	MWs	$2,000	$250,000	See Cost Worksheet 5
SUBTOTAL				$2,590,000	
Contingency	30%		$2,590,000	$777,000	10% Scope + 20% Bid
SUBTOTAL				$3,367,000	
TOTAL ANNUAL O&M COST				**$3,370,000**	

PERIODIC COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Monitored Natural Attenuation Sampling	125	MWs	$1,000	$125,000	See Cost Worksheet 5. Assume MNA Sampling during Yrs 1 - 4
Subtotal				$125,000	
Contingency	30%		$125,000	$37,500	10% Scope + 20% Bid
SUBTOTAL				$162,500	
TOTAL ANNUAL PERIODIC COST				**$163,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$37,450,000	$37,450,000	1.000	$37,450,000	
18	ANNUAL O&M COST	$60,660,000	$3,370,000	10.059	$33,899,123	18 year O&M period
4	PERIODIC COST	$652,000	$163,000	3.387	$552,115	
		$98,762,000			$71,901,238	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$71,900,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).

Alternative: **Alternative I** — **COST ESTIMATE SUMMARY**

Name: **Limited Air Injection/Vapor Removal and Monitored Natural Attenuation**

Site: Kelly Air Force Base, Texas
Location: Zone 4 Shallow Groundwater
Phase: Corrective Measures Study
Base Year: 2000
Date: 4/16/02 14:27

Description: Air injection and vapor removal (air sparging/SVE) applied specifically to those areas of the plume with TCE concentrations at or above 100 ppb and monitored natural attenuation throughout the contaminated area.

CAPITAL COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Corrective Measure					
Air Sparge/SVE Wells	5,000	Wells	$3,000	$15,000,000	See Cost Worksheet 10
Monitoring Wells	25	EA	$2,000	$50,000	See Cost Worksheet 3
Air Injection/Vapor Treatment System	10	EA	$214,000	$2,140,000	See Cost Worksheet 11
SUBTOTAL				$17,190,000	
Contingency	25%		$17,190,000	$4,297,500	10% Scope + 15% Bid
SUBTOTAL				$21,487,500	
Project Management	5%		$21,487,500	$1,074,375	USEPA 2000, p. 5-13, >$10M
Remedial Design	6%		$21,487,500	$1,289,250	USEPA 2000, p. 5-13, >$10M
Construction Management	6%		$21,487,500	$1,289,250	USEPA 2000, p. 5-13, >$10M
SUBTOTAL				$3,652,875	
TOTAL CAPITAL COST				**$25,140,000**	

OPERATIONS AND MAINTENANCE COST

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Annual Groundwater Monitoring	125	MWs	$2,000	$250,000	See Cost Worksheet 5
Vapor Treatment System	10	EA	$108,000	$1,080,000	See Cost Worksheet 11
AS/SVE wells	5000	EA	$1,000	$5,000,000	See Cost Worksheet 10
SUBTOTAL				$6,330,000	
Contingency	30%		$6,330,000	$1,899,000	10% Scope + 20% Bid
SUBTOTAL				$8,229,000	
TOTAL ANNUAL O&M COST				**$8,230,000**	

PERIODIC COSTS

DESCRIPTION	QTY	UNIT	UNIT COST	TOTAL	NOTES
Monitored Natural Attenuation Sampling	125	MWs	$1,000	$125,000	See Cost Worksheet 5. Assume MNA Sampling during Yrs 1 - 4
Subtotal				$125,000	
Contingency	30%		$125,000	$37,500	10% Scope + 20% Bid
SUBTOTAL				$162,500	
TOTAL ANNUAL PERIODIC COST				**$163,000**	

PRESENT VALUE ANALYSIS

Discount Rate = 7%

End Year	COST TYPE	TOTAL COST	TOTAL COST PER YEAR	DISCOUNT FACTOR (7%)	PRESENT VALUE	NOTES
0	CAPITAL COST	$25,140,000	$25,140,000	1.000	$25,140,000	
18	ANNUAL O&M COST	$148,140,000	$8,230,000	10.059	$82,786,285	18 year O&M period
4	PERIODIC COST	$652,000	$163,000	3.387	$552,115	
		$173,932,000			$108,478,401	
	TOTAL PRESENT VALUE OF ALTERNATIVE				**$108,480,000**	

SOURCE INFORMATION

1. United States Environmental Protection Agency. July 2000. A Guide to Preparing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. (USEPA, 2000).